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Carr,
J. A.

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FINAL REPORT

IMPACTS OF GROUND EXTRACTION SYSTEMS DURING HARVEST OF HARDWOODS ON STEEP SLOPES

Dr. William B. Stuart
Associate Professor
Jeffery A. Carr
Graduate Student
VPI & State University
Blacksburg, Virginia

and

Mr. Donald L. Sirois
Engineering Project Leader

George W. Andrews Forest Sciences Laboratory
Auburn University, Alabama

Southern Forest Experiment Station

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HARVESTING IMPACTS ON STEEP SLOPES IN VIRGINIA

by

Jeffery A. Carr

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APPROVED:

William B. Stuart, Chairman

Thomas W. Reisinger

James A. Burger

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Blacksburg, Virginia

Harvesting Impacts on Steep Slopes in Virginia

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Jeffrey A. Carr

W. B. Stuart, chairman

Forestry

(Abstract)

This purpose of this study was to assess ground disturbance from harvesting hardwood stands with conventional rubber-tired skidders on slopes greater than 30 percent in Virginia. Special emphasis was placed on erosion, compaction and soil movement. Ten randomly selected study areas were clear-cut between September 1988 and August 1989; measurements followed between March 1989 and August 1989. Potential erosion was estimated using the Universal Soil Loss Equation and soil mechanical strength was measured with a cone penetrometer. Volumes of soil movement resulting from skid trails, landings, and waterbars were measured. Circular plots were used to estimate the percentage of each tract in seven disturbance classes. Descriptive data documented during the study includes land ownership, precipitation records, soil survey information, equipment (make, model, tire size), and volume of the products removed during harvesting.

Results show a relatively small amount of soil disturbance associated with harvesting these tracts. Erosion estimates for seven of the ten tracts were below 1.08 tons/acre/year and only one was greater than 3.0 tons/acre/year. The erosion potential for these areas will decrease with time as vegetation increases. The primary source of ground disturbance within the harvested areas was due to skid trails, which occupied 3 to 10 percent of the ground surface. Tracts using overland skid trails experienced far less disturbance than those with bladed skid trails. Following harvest, the undisturbed area ranged from 73 to 81 percent on the ten study tracts.

Scheduling practices, tract layout, and tract closure techniques concentrated in high risk spots, can greatly reduce the impact of harvesting steep slopes.

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Introduction

Over the past decade the source of wood supply for central and western Virginia has been shifting from convenient, gently sloping terrain toward less accessible, steeper terrain. Areas having average slopes greater than 30 percent are now accounting for a larger share of the available timber supply for some mills. This move to steeper slopes, combined with an increasing public concern for water quality and aesthetics of forested areas, poses a potential obstacle for many wood-using industries with a land and timber-supply base in the Appalachian region.

The Appalachian mountain region is a key component of the water supply system for much of the eastern United States. Rivers and streams which serve many of the metropolitan areas from Boston, Massachusetts to Savannah, Georgia originate in this region. Recreation areas in the Appalachians serve more than half the U.S. population. For these reasons, water quality and aesthetics in the Appalachians are major focal points of public concern. Commercial sawmills, pulp mills, and other specialty industries constitute a large percent of the small, rural economy in this area. The public will not tolerate deforestation to the extent of that in the late 1800's; at the same time, recreation and aesthetics alone will not support a healthy and diverse economy in the Appalachian region.

In order to successfully address public concern in these areas, forest industry must develop and demonstrate methods for logging steep areas which minimize real or perceived detrimental harvesting effects. These include minimizing stream sedimentation, soil compaction on landings and skid trails, soil moved in earthworks, and post harvest soil erosion. The public will not ignore careless harvesting practices.

Constraints in the form of regulations, environmental impact statements, best management practices (BMP's), and other challenges to timber production provide means for expressing their opinions. Although facts are seldom a defense against emotion, a more complete understanding of the impacts of conventional harvesting system operation on steep slopes can provide a basis for explanation, response, and planning.

Some soil disturbance is inherent in timber harvesting, regardless of the method used for in-woods transport. Investigations concerned with site degradation have shown that site damage can be reduced by job planning, equipment selection, operation execution, and post-harvest site treatment. Generally, these studies have been associated with coastal plain, piedmont and west coast operations. Relatively few have dealt with current harvesting systems in the Appalachians, particularly rubber-tired skidding systems.

This study was an initial step for documenting site impacts of harvesting on steep slopes and providing a basis for developing strategies directed at further reduction of the detrimental aspects of operating on these areas. The objectives of this study were:

a) to document the form and extent of soil disturbance and compaction associated with conventional timber harvesting operations on steep slopes in Virginia;

b) to identify this disturbance and compaction with specific forms of causality in planning, operation, and closure; and

c) to make recommendations for reducing these impacts with emphasis on minimizing the effects of future operations.

Financial assistance was in part provided by the U.S. Forest Service, Engineering Research Unit at Auburn, Alabama. Assistance in locating study sites and developing field procedures was provided by an advisory group from industry and the public sector. This group included representatives from Westvaco Corporation, Georgia-Pacific Corporation, Nekoosa Packaging Division of Great Northern Nekoosa Corporation, and the U.S. Forest Service, Jefferson National Forest.

Literature Review

The forests in the Appalachian region are diverse in geology, species composition, soil type, accessibility, and economic importance. One characteristic common to all areas is slope. Slope complicates harvesting by decreasing both crew and machine productivity, increasing erosion risk, and requiring special care in road construction, landing construction, and harvesting applications. Rummer and Sirois (1984) estimated that the productivity of conventional harvesting systems decreased noticeably on slopes greater than 20 percent. Crew performance on 70 percent slopes was reduced to one third of that on level ground. There is an increase in safety hazards which accompanies the decrease in production. Skidding is one of the more dangerous activities on steep slopes. If care is used to select the proper skidder and tire size, conventional equipment can be used on 30 to 40 percent slopes without undue risk to either machine or operator (Samset, 1984). Excavated skid trails are required on slopes greater than 40 percent, unless the operator can maneuver perpendicularly to the contour.

Alternatives to Conventional Skidders

Wide tires offer promise as a method to reduce site impacts. Wide tires, those greater than 32 inches in width, have only recently been considered a steep slope

modification to rubber-tired skidders. Gao (1985) verified that for every 3.5 inches of tire width, the critical tipping angle for the machine decreased by one degree. Wide tires not only increase stability, but can be helpful in decreasing site degradation. Gao's study also demonstrated significant decreases in wheel slippage in uphill skidding with increased tire width. Wide tires (66x43-25) had less wheel slippage compared to more commonly used tires (24.5-32) in 50 percent of his measurements on slopes of 20 to 30 percent. Cone-penetrometer readings for 66x43-25 tires were one-tenth that of 24.5-32 tires on a 25 percent slope.

Crawler tractors are commonly believed to cause less soil compaction than rubber-tired skidders. Burger et al. (1985), working on soils of a clayey Hapludult family, found that soil compaction resulting from an unloaded crawler tractor with a calculated ground pressure of 8.7 psi was not significantly different from that of an unloaded rubber-tired skidder with a ground pressure of 33.4 psi. This supports reasoning that rubber-tired skidders may be no more of a threat to soil compaction than crawler tractors (Burger et al., 1985). As the ground pressure of a machine decreases, compaction generally decreases. Lowman et al. (1978) demonstrates that wide tires with low air pressure can reduce pressure of the machine on the soil by spreading the load over a larger area..

There have been several studies dealing with differences in surface disturbance, soil compaction, erosion, and sedimentation between cable yarders and rubber-tired skidders (Dyrness, 1965, McMinn, 1984, Miller and Sirois, 1986, Krag and Webb, 1987). In a study comparing a small cable yarder with a cable skidder in north Georgia, McMinn (1984) found that the cable skidder exposed 37 percent of the soil while one percent of an adjacent area was exposed by the cable yarder. Miller and Sirois (1986)

found that ground skidding affected 31 percent of a harvested area; 16 percent was affected by a cable skyline. In Oregon, Dyrness (1965) compared soil disturbance from high-lead systems with tractor logging and found that 27 percent of the soil was compacted by tractor logging, while only 9 percent was compacted with the cable system. He also states that tractor logging left 36 percent of the harvested area undisturbed, while 57 percent was left undisturbed by cable yarding.

Although alternatives such as cable yarders appear to decrease adverse effects to the environment (Miller and Sirois, 1986), the additional cost, specificity, and complexity of these systems result in continued use of rubber-tired skidders by the majority of loggers in Virginia.

Decreasing site disturbance from conventional harvesting methods may also be accomplished by a dispersed, overland skid trail pattern. There appear to be two conflicting viewpoints associated with this topic, each with their advantages. The first is that restricting severe impacts to a smaller area is better. Froehlich et al. (1981) report that an efficient system of designated skid trails can reduce area of compacted soil by at least two-thirds. Designated skid trails reduce compacted area by restricting machine travel to fewer trails, thus increasing winching logs to the machine instead of traveling to the stump. This produces a more severe impact on a small area. Dispersed skidding which avoids multiple passes over any one area, is an alternative which both reduces planning efforts and costs. Wimme (1985) states that dispersed skidding resulted in the least overall site impact. Although a larger area was impacted by harvesting, this impact was less severe than that of designated skid trails, and required a shorter recovery period to return to its original level of productivity.

Erosion

There are several components of site disturbance that occur on clear-cuts; these include litter removal, soil compaction, rutting, and soil movement by road and landing construction. All have the potential to increase the risk of sedimentation. Soil movement may take two forms. The soil may be simply moved from one location to another on the tract. Wischmeier and Smith (1978) state that soil material eroded from a field slope may be deposited in the field boundaries, in terrace channels, in depressed areas, or on flat or vegetated areas traversed by the overland flow before it reaches a stream. They also maintain that sediment of this type, deposited near its place of origin, is not directly relevant to water quality control. The soil may also be carried from the forest floor into a stream, increasing sedimentation and decreasing water quality.

Erosion is largely a function of the amount of exposed soil (Dissmeyer and Foster, 1984). Cover such as litter, slash, logs, and surface rock protects the surface from the erosive forces of raindrop impact and runoff. "Protected and undisturbed forest soils have infiltration rates that usually exceed rainfall intensity. Exposed forest soils are subject to soil detachment by raindrop impact. Also, they yield surface runoff, which potentially erodes soil and transports detached soil from the slope" (Dissmeyer and Foster, 1984). One way of increasing cover and subsequently decreasing erosion is to distribute slash over road surfaces and other patches of bare soil. Slash cover offers protection to the soil surface until vegetation can be established (Berglund, 1978).

Additional factors related to erosion include, the presence or thickness of an organic layer, the presence or concentration of fine roots in the surface layer of the soil, height and percent coverage of a canopy, percent slope of the area, slope length, type of

soil, amount of annual rainfall in the area, on-site storage, and the amount of steps on the site (Dissmeyer and Foster, 1984).

Douglass (1975) estimates that 0.15 tons/acre/year soil loss is normal geologic erosion from a fully stocked southeastern forest. All land, even virgin forests, is subject to some degree of erosion. Other estimates of normal geologic erosion range from 0.18 to 0.30 tons/acre/year. However, these rates apply to an entire landscape and include areas where erosion is accelerated by such activities as highway construction, urbanization, and agriculture (Patric, 1976). In carefully managed, undisturbed watersheds on the Fernow Experimental Forest near Parsons, West Virginia, most sediment results from erosion of stream channels (Kochenderfer et al., 1987). Five Fernow watersheds under varying management practices averaged between 0.001 and 0.003 tons/acre/year over a 20-year period (Reinhart et al., 1963). The soil loss from several forested watersheds in the eastern and western regions of the United States show 0.25 tons/acre/year to be a suitable estimate of sediment yield. These estimates, although referred to as "ball park" figures derived for specific locations, are surprisingly consistent (Patric et al., 1984).

These figures are much less than estimates of "tolerable" soil loss to sustain production of fertilized agricultural land, which ranges from 2 to 5 tons/acre/year (Wischmeier and Smith, 1978). These site production figures should not be confused with tolerable limits of sedimentation for acceptable water-quality. Foth (1978) states that erosion at approximate rates of 1 inch every 1000 years is beneficial to site productivity in forested areas. These small amounts of erosion counteract leaching of various nutrients from the soil.

In a study on steep slopes, near Newport, Virginia, using an FMC 180 logging tractor, the USDA-Forest Service (1984) found that leaving 22.4 percent of the soil exposed (of which 15.8 percent was covered by slash and leaves) resulted in estimated soil loss well below the calculated tolerable level of soil loss for that site. This tolerable level of soil loss was calculated using the *Guide for Calculating Tolerable Accelerated Soil Loss for Forested Lands in the Southern Region* (USDA Forest Service, 1982). The Forest Service estimated potential soil loss, using the Universal Soil Loss Equation, of 0.25 tons/acre/year compared to the tolerable level of 0.59 tons/acre/year. Bladed skid trails were not used in this study (Rummer and Sirois, 1984). This clearly shows that steep slope harvesting is possible without severe erosion risk.

Scattered small patches of bare soil including soil exposed by felling trees, skidder wheel slippage away from trails, and exposed soil from winching logs, are seldom an erosion risk. "Research indicates that rain falling on scattered small patches of bare soil will not deliver sediment to streams unless these patches form unbroken pathways over long downhill distances" (Virginia Dept. of Forestry, 1989). Up to 25 percent of an area can be exposed mineral soil without serious erosion if there are frequent patches of organic material to stop initial soil movement (Dissmeyer and Foster, 1984).

Fortunately, erosion as a result of logging is usually short-term. Only on poorly planned harvests does erosion remain a problem for more than 2 or 3 years after logging has been completed. Turbidity, expressed as parts of soil per million parts of water, averaged 490 ppm for a 13 month-long operation. Average turbidity dropped to 38 ppm during the first year following the harvest and to 1 ppm during the second year (Hornbeck and Reinhart, 1964).

Major disturbances such as mineral soil exposure, soil movement, and compaction tend to be intrinsically related to landings, skid trails and spur roads (Miller and Sirois, 1986). These earthworks have a very high erosion risk, due to the large amount of exposed soil, which is further escalated when the structures are poorly located or maintained. These areas especially deserve concentrated attention to minimize erosion risk because they are usually easily accessible, small in area, and easily treated.

Seeding is a common post harvest treatment which increases cover and root stabilization of soil (Berglund, 1978). One method of reducing erosion risk on compacted sites is to till compacted surface layers before seeding to enable maximum root elongation (Cannell, 1977). Reisinger et al. (1988) add that the most effective treatment for compacted soils on skid trails and landings is tillage of the surface soil combined with fertilization and seeding. This treatment is successful at stabilizing soil at a higher rate than seeding an untreated, compacted surface.

Soil Compaction

Soil compaction decreases macropore space, aeration, water infiltration rate, and saturated hydraulic conductivity, and to increase mechanical strength and bulk density (Blackwell and Soane, 1981). Decreased macropore space slows infiltration and can lead to increased surface runoff and sedimentation (Dissmeyer and Foster, 1984). From a biological standpoint, the ability of a soil to store and conduct water and air is probably the most important property affected by compaction (Burger et al., 1985). According to Patric (1980), compaction and infiltration rates were negligibly affected by clear-cutting on the Fernow Experimental Forest near Parsons, West Virginia. Rainfall was observed

to infiltrate the forest floor as fast as it fell, then moved through, not over, the soil to the streams.

The number of skidder passes over a specific location is important. Forest soil compaction during harvest depends on the weight and function of the machine used, the amount of surface litter and slash, soil texture and structure, and the soil moisture level (Burger et al., 1985). According to Wimme (1987), up to 9 passes in moist soil conditions (10% soil moisture content) have little impact on soil compaction and water movement. The presence of litter and slash on the soil surface increases the soil's ability to resist compaction by spreading the load of the equipment and subsequently decreasing tire penetration into the soil. In a study by Mace (1970) on forest soils in northern Minnesota, two harvesting operations were compared, one using full tree skidding, and the other using tree length skidding. He found that compaction was significantly less when using tree length skidding. This decrease was attributed to large amounts of slash spread over the operation areas.

Some soil compaction is necessary for tree growth and can be beneficial to tree roots (Greacen and Sands, 1980). Forest soils, unlike agricultural soils, are subject to compactive forces of root extension which may cause differences in soil strength distributions (Adams and Froehlich, 1981). Forest soils, for the most part, have never been subjected to tilling and, therefore, exhibit more heterogeneity than agricultural soils. The amount of surface stone is often large and interferes with many sampling methods used to measure compaction. This variability of forest soils emphasizes that caution is needed when dealing with indicators of compaction.

The soil compaction process is essentially a reduction in volume for a given mass of soil, caused by externally applied pressure. The most direct quantitative

measurements of soil compaction and most frequently used to express changes due to machine traffic are soil bulk density and porosity (Reisinger et al., 1988). Increases of soil bulk density are usually experienced with compaction. For example, Wimme (1985) found bulk densities of a moist, sandy loam soil (10.9 - 26.7 % moisture content) to increase an average of 0.14 g/cc with 1 to 27 skidder passes. Most of this increase was attributed to the first pass. Also, Koger et al. (1984) found an increase in bulk density, on a sandy loam soil, of 0.25 g/cc with one pass of a single-wheel tire tester (simulating skidder traffic). With four passes, they found an increase of 0.29 g/cc. In the same study, soil mechanical strength increased 52 psi with one pass and 84 psi with four passes.

Higher soil strength increases a soil's ability to resist compaction. Subsoil, having a naturally higher mechanical strength than surface soil, is more resistant to compaction (Greacen and Sands, 1980). Subsoil should not be considered compacted simply on the basis of mechanical strength. (Further assessment of additional factors should be considered before subsoil is labeled compacted.)

A mechanical strength of 362 psi (2500 kPa) is often regarded as critical for root growth. Plants roots may continue to grow in soils with mechanical strengths up to 1160 psi (8000 kPa), but at a much slower rate (Greacen and Sands, 1980). Taylor and Gardner (1963) found that root growth decreased by 30% in soil with a strength of 210 psi. Growth decreased by 70% when soil strength was 420 psi. Past studies are consistent in their reports on root elongation with respect to soil mechanical strength in that root growth of woody plants appears to drop off significantly at 362 psi (Zyuz, 1968, Greacen et al., 1968, and Sands et al., 1979).

Using a cone penetrometer to measure cone resistance (cone index) is a common empirical measure of soil strength (O'Sullivan et al., 1987). The use of cone penetrometers for determining soil penetration resistance is one of the more convenient methods to indicate soil compaction, soil strength, and impedance to root penetration. Cone resistance is a point estimate, rather than a bulk soil measurement, and tends to be highly variable even within small areas. This variability is often associated with roots or stones below the ground surface (Anderson et al., 1980). Although there are some differences among penetrometer methods, they appear to be a reliable alternative to other measures (Sirois et al., 1989).

Categorizing Site Disturbance

Miller and Sirois (1986) developed seven site classifications for the disturbance caused by harvesting operations in Southeastern forests. This classification system uses four disturbance categories (undisturbed, slightly disturbed, severely disturbed and depression deposits) and three categories to further characterize the disturbance (debris piles, compaction, and non-soil).

1) **Undisturbed** - litter still in place and no evidence of compaction.

2) **Slightly disturbed** includes any of three conditions:
   a) Litter removed and mineral soil exposed;
   b) Mineral soil and litter mixed, about 50%;
   c) Mineral soil deposited on top of litter to a depth of 5 cm.

3) **Severely disturbed** - surface soil removed and the subsoil exposed.

4) **Compacted** (depressed) - obvious compaction by passage of a machine or log.

5) **Depression deposit** - sedimentation in holes, troughs, or behind debris dams.

6) **Debris piles** - slash exceeding 30 cm deep that would hinder planting even after burning.

7) **Non-soil** - rock outcrops, streambeds, and tree stumps.

This classification system is more complete and better defined than others such as that used by USDA Forest Service (1984) which has the following categories on a point estimate basis: bare soil, no bare soil, rock, log, detached leaves with bare soil beneath, or attached leaves with bare soil beneath.

In Miller and Sirois' classification scheme, debris piles were considered to be a problem for post harvest regeneration activities where their study was conducted. This differs from steep slope hardwood areas where slash is advantageous, serving as a barrier for slowing water movement and resisting subsequent erosion.

The literature reviewed presented and compared several alternatives to conventional skidders including wide tires, cable systems, and crawler tractors. Although, none of these have been successful at replacing the conventional rubber-tired skidder, they have been able to decrease surface disturbance, erosion, and compaction during timber harvesting. Timber harvesting impacts are often difficult to measure; however, as methods continue to improve, a better understanding of their effect on the environment will evolve.

Methods and Procedures

Study Area Selection

The cooperators in the project, Westvaco, Georgia-Pacific, Nekoosa Packaging, and the U.S. Forest Service, were asked to submit tracts for possible inclusion based upon the following criteria: only clear-cuts would be considered, average slope would exceed 30 percent, and the date of harvest would be between September, 1988, and September, 1989. The tracts were to be selected without regard to the apparent "quality" of the logging job. Prescreening to select only the best operations was explicitly discouraged. As a result, 29 separate tracts were identified, and 10 were selected for detailed study. This final selection attempted to assure a diversity of equipment used; overland travel and bladed skid trails; uphill, downhill, and contour skidding; soil type; ownership; and season of cut. None of the tracts were visited prior to selection to further ensure impartiality.

The Virginia Department of Forestry was preparing to initiate voluntary "Best Management Practices" (BMP's) at the time most of these tracts were cut, but inspection procedures had not begun. A series of workshops on BMP's and suggested harvesting techniques to minimize erosion and water quality degradation had been

conducted in the area where most of the tracts were located. Consequently, the loggers performing the harvests were likely aware of the need to harvest in a quality manner, but were under no formal requirements to do so other than those in normal contract agreements.

Maps and descriptions of each tract can be found in the next section along with additional detail pertaining to soils, topography, layout, drainage pattern, season of the harvest, and other characteristics of interest. When a study area was selected, maps of the location were acquired either from the property owner or the timber purchaser. Topographic maps, soil surveys, weather data for the period of the harvests, and other descriptive information were obtained.

A two-person study team visited each tract to collect information regarding the manner in which the harvests were performed and the condition in which the sites were left after harvest. Two forms (included in Appendix A) were used for field documentation of the site characteristics. The first form was used to document general information about the physical layout of the harvesting location (i.e., the location of roads, landings, skid trails, rock outcrops and other gross tract features). This was then supplemented by detailed sampling procedures using 20-foot diameter plots located at 50-foot intervals along contours of the tract. The original study design called for adjusting the distance between plots perpendicular to contour to achieve a 10 percent sample of the tract. Because of time limitations and the difficulty associated with the plot survey system on steep slopes covered with slash, an average of 5 to 8 percent sample was achieved on the study areas.

At each plot center, slope percent was determined at a point perpendicular to the contour and skid direction to the landing site (i.e., up/downhill, on contour, or rolling)

was recorded. A ten-foot pole was used to define a circular plot about that center. The disturbance classes encountered within the plot were sketched on the data collection form. Measurements of the depth of the organic layer, soil texture, and other characteristics of each disturbance class were noted and recorded. Live brush density and the parameters required by the Universal Soil Loss Equation adapted to forested sites were recorded along with comments that would be useful in subsequent data analyses. Plots were installed on skid trails, landings and roads as well as the forest floor to assure that all classes of soil disturbance and erosion risk were documented.

A total of 1120 plots were installed on the 10 study tracts. These were further supplemented by measurement and documentation of engineered earthworks such as road cut and fill, landing cut and fill, truck turnaround construction, and non-engineered earthworks such as skidder blade work on skid trails, waterbar construction, and the movement of troublesome stumps and rocks. These on the ground sketches were supplemented by aerial photographs taken of each tract from which scale and planimetric measurements were used to verify field measurements. Field work spanned from late March, 1989 to late September, 1989. Aerial photographs were taken in October, 1989, and many of the sites were revisited to verify some of the data measurements in November, 1989.

A cone penetrometer (with a cone base 0.798 inches diameter) was used to measure differences in soil mechanical strength within undisturbed, slightly disturbed, severely disturbed, and noticeably compacted areas. The mechanical strength of depression deposits was not measured because of the small amount of area occupied by this class. On each plot, cone penetrometer measurements were taken at random points within each disturbance class present. Each measurement was taken to a six inch depth

(read at 1-inch intervals). This required a two-person team; one forcing the penetrometer at right angles into the soil surface at a rate of 1 inch every 5 seconds, while the second recorded values from the penetrometer gauge. To assure consistency, these task were relegated to the same individual for the entire study. If the six inch reading was precluded by bedrock, rock fragment, or roots and other obstructions, several attempts were made to acquire a valid reading. Despite this search for a feasible location, many areas were so occluded that penetrometer readings were impossible. Severe compaction on some plots exceeded the capacity of the cone penetrometer's scale (236 psi). When this occurred, soil strength readings were recorded as greater than 236 psi.

The soil surface conditions on each plot were categorized using a system adapted from Miller and Sirois (1986). The classes used for this study are listed with their respective sub-classes as follows:

1) **Undisturbed** - litter still in place and no evidence of compaction.

Sub-classes - **non-soil** (rock outcrops, streambeds, and stumps);
debris piles (slash exceeding 30 cm deep);

2) **Slightly disturbed** includes any of three conditions:
a) Litter removed and mineral soil exposed;
b) Mineral soil and litter mixed, about 50%;
c) Mineral soil deposited on top of litter to a depth of 5 cm.

Sub-classes - **compaction** (obvious depression by passage of machine or log);
debris piles.

3) **Severely disturbed** - surface soil removed and the subsoil exposed.
a) Cut or rutted soil consisting of soil in its original location;
b) Pushed or fill soil which has been moved during harvesting activities.

Sub-classes - **compaction**;
debris piles.

4) **Depression deposit** - sedimentation of soil in holes, troughs, or behind debris dams.

The site disturbance classification system used in this study is very similar to that used by Miller and Sirois (1986); however, the following differences exist: in their system, only one category at a time was used to describe the ground surface. All seven variables (when summarized) added to 100 percent of the tract's surface. The modified version used for this study classified the ground surface in two ways: first, the area was assessed using four "primary" classes of undisturbed, slightly disturbed, severely disturbed, and depression deposits. Together, these covered 100 percent of the tract surface.

The remaining "sub-classes" (compaction, non-soil, and brush) were used to further describe the "primary" classes. Compacted areas co-existed with slightly disturbed and severely disturbed classes. For example, a portion of a plot displayed slightly disturbed characteristics, and was noticeably compacted, it would be labeled slightly disturbed/compacted. Similar recording methods applied to debris piles. The non-soil class was considered undisturbed since non-soil cannot be disturbed.

Data Summarization

The first step in the data summarization involved estimation of the percent of tract surface in each of the disturbance classes. The plots which contained a single disturbance class were tallied. A dot grid was used for estimating the plot area (in percent) of each class on the plots which contained only 2 or 3 disturbance categories and exhibited rather simple configurations. For more complex plot diagrams, the boundaries of each disturbance class were digitized using a special-purpose computer

program written for this study. This program computed the area within each configuration on the plot, converted this to a percentage of the total plot area, and loaded the data into a spreadsheet for subsequent analyses. Data from all three data collection forms were then combined to develop an overall estimate of the percent of tract surface in each soil disturbance class. A estimate of soil movement was added to this plot information using the Universal Soil Loss Equation modified for forested sites. This equation and its factors, listed below, are defined in detail in *A Guide for Predicting Sheet and Rill Erosion on Forest Land* (Dissmeyer and Foster 1984).

$$A = R * K * L * S * C * P$$

where:

A = Tons of soil movement per acre per year;

R = 150 (Rainfall and runoff factor);

K = Soil erodibility factor (varied for each soil series);

LS = Topographic factor (slope length and percent; varied for each plot);

C = Sub-factors (all subfactors varied for each plot)
Bare soil and fine roots
Canopy
Step factor
Depression storage factor
Organic Content factor;

P = Support practice factor. Not used (for short term agricultural use only).

Individual estimates of soil movement were made for each of the 1120 study plots; however, missing data values on several plots forced omission of their estimates. An additional estimate was calculated using average parameters for each tract. This

represented total soil loss (stream sedimentation) from the tract as opposed to on-site soil movement.

Cone penetrometer readings within the soil disturbance classes on each plot were paired with an undisturbed reading within that plot from an undisturbed area immediately adjacent to that plot. Analyses were conducted differences between penetrometer readings of the undisturbed class and those from other disturbance classes. For the purpose of this study, areas with readings above the scale of the penetrometer (236 psi) were defined as compacted.

Soil moisture content is an important co-variable when estimating soil mechanical strength, but it was not possible to take moisture content samples from all 1120 plots during the data collection period. Consequently, it was assumed because of the relatively small plot size and short time interval between undisturbed and disturbed measurements, that soil moisture was constant at the time of measurement.

Skid Trail Percentages

Estimates of the total area covered by noticeable skid trails were developed from the length and width measurements collected in the field. These figures were verified by comparing measurements taken from the aerial photographs and on-ground measurements. The surface area in skid trails was then divided by the total tract area and multiplied by 100 to arrive at an estimate of the percent area covered by skid trails.

Areas of overland skid trails, (those which involved no surface preparation prior to use) were recorded separately from areas of bladed skid trails (trails which were

constructed prior to harvest or required soil to be excavated). Both trail types were then summarized as the total area under trails for each tract.

Engineered Earthworks

Soil volumes moved primarily for road and landing construction, were calculated using standard earthwork formulae. Figure 1 illustrates measurements taken for estimating soil volumes moved in road construction. These estimates included only roads constructed for the sole purpose of harvesting the specific study tract. Permanent roads and harvest access roads which crossed a study tract, but served other tracts were excluded. This was done because of the difficulty in developing an equitable method for apportioning the percentage of the disturbance attributable to the soil volume removed from a study tract against that attributable to other road use.

In most instances, the original terrain at landing locations was difficult to visualize and measure for estimation of soil movement. Compaction, debris build-up, stump removal, and dense brush along the perimeter of many landings added to the difficulty of accurately estimating soil movement. The estimates developed were based on cut and fill estimates and are believed accurate to a few cubic yards.

Waterbars

The volume of soil moved was estimated for each waterbar installed as a part of tract closure. The procedures used for soil volume measurement are shown in Figure 2.

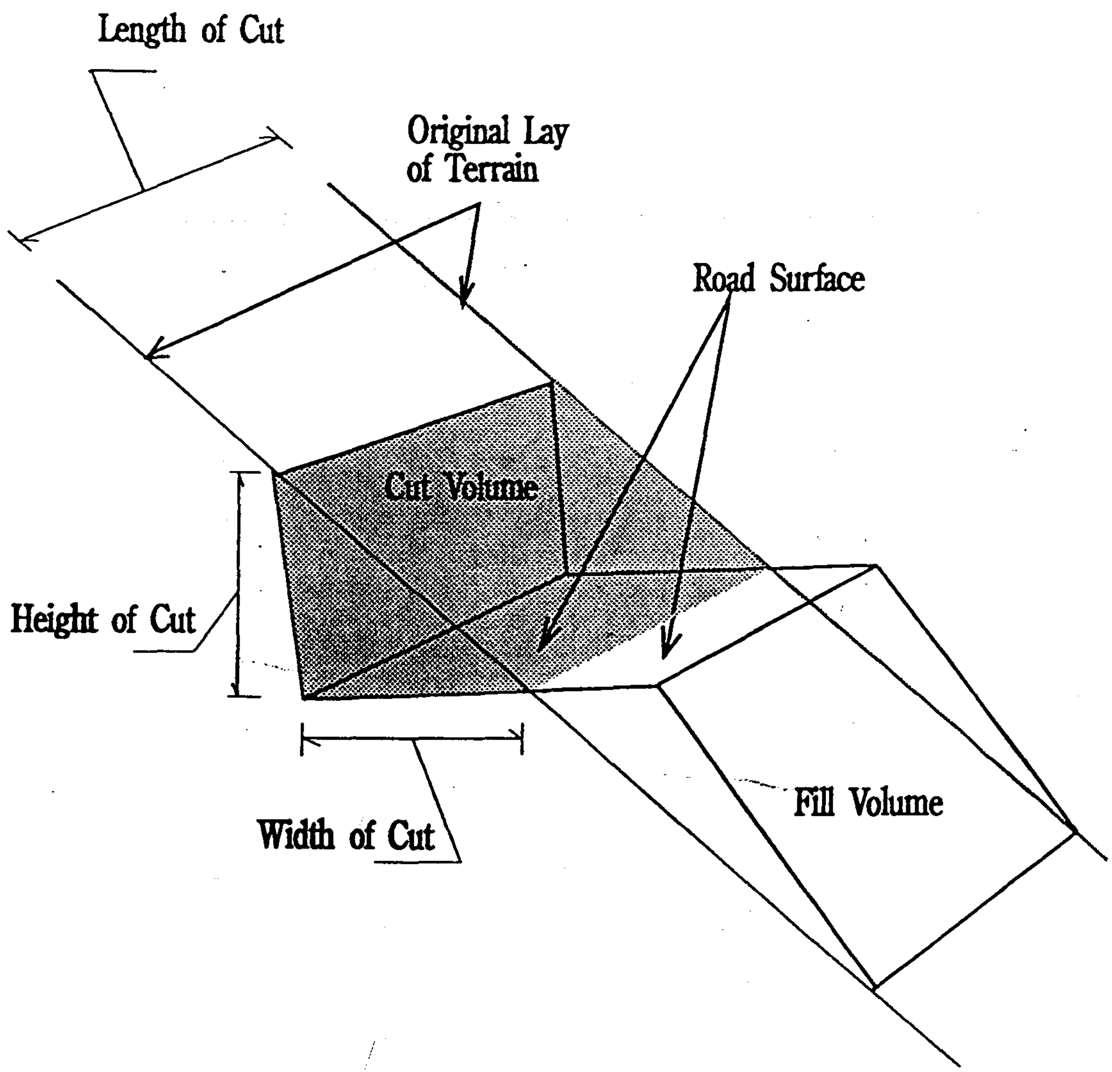


Figure 1. Soil volume measurement methods for roads.

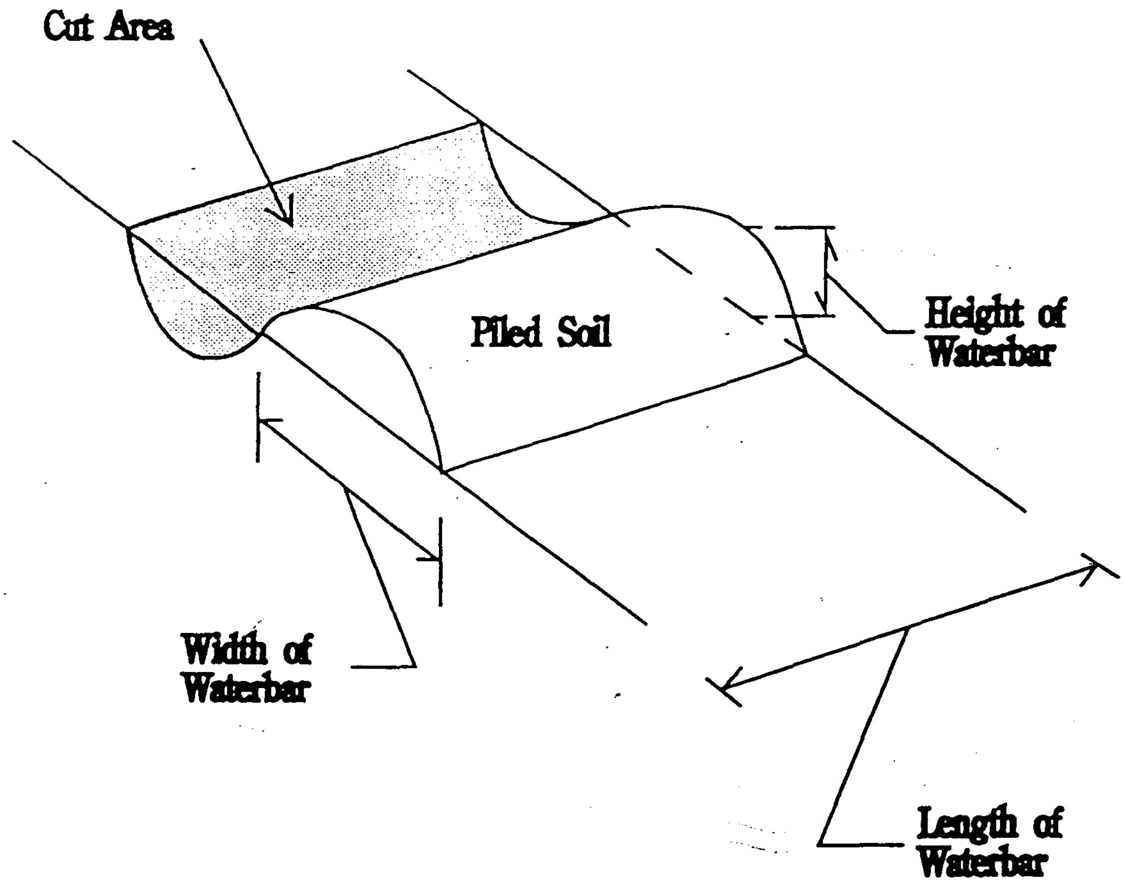


Figure 2. Soil volume measurement methods for waterbars.

Data Analysis

Histograms of estimated soil movement were developed for each tract. A single soil loss estimate for each tract was also calculated based upon the average values for the equation parameters. The percent of each tract in each of the disturbance classes was estimated from the plot data. Paired t-tests were used to analyze the change in soil mechanical strength between each disturbance class and undisturbed areas. These analyses were then used to verify the classification done during the field work.

Information on the percent area in skid trails and the amount of soil movement associated with road, landing, and waterbar construction were summarized for each tract. Comparisons were developed between similar tracts representing different harvesting strategies and operating methods. These comparisons included up and downhill skidding versus contour skidding; the use of constructed versus overland skid trails, and differences in waterbar construction and tract closure techniques.

RESULTS AND DISCUSSION
(Results)

The Results and Discussion section is divided into two parts. The results section will center around the ten study tracts giving detailed descriptions of individual tract characteristics. The discussion section will concentrate on comparisons between tracts, referring periodically to the site descriptions.

Site Descriptions

The locations of the ten sites, arbitrarily identified as tracts A through J, were roughly bounded by West Virginia on the north, Buena Vista on the east, Bedford on the south, and Covington on the west (Figure 3). The areas selected included a variety of soil types, ownerships, tract sizes, slopes, and aspects (Table 1); and a variety of harvesting traits including season of harvest, skid trail type, equipment used for the harvest, skidding direction, and harvested volume (Table 2). Logging methods for all study tracts were similar, consisting of partial to full delimbing and topping at the stump, tree length skidding to the landing by rubber-tired skidder, and bucking to log length at the landing.

Tract A

Tract A (11 acres), the first tract evaluated, is located in Botetourt County on forest land owned by industry and managed for pulpwood production. It had the steepest average slope of all the study tracts (43 percent) and was harvested using

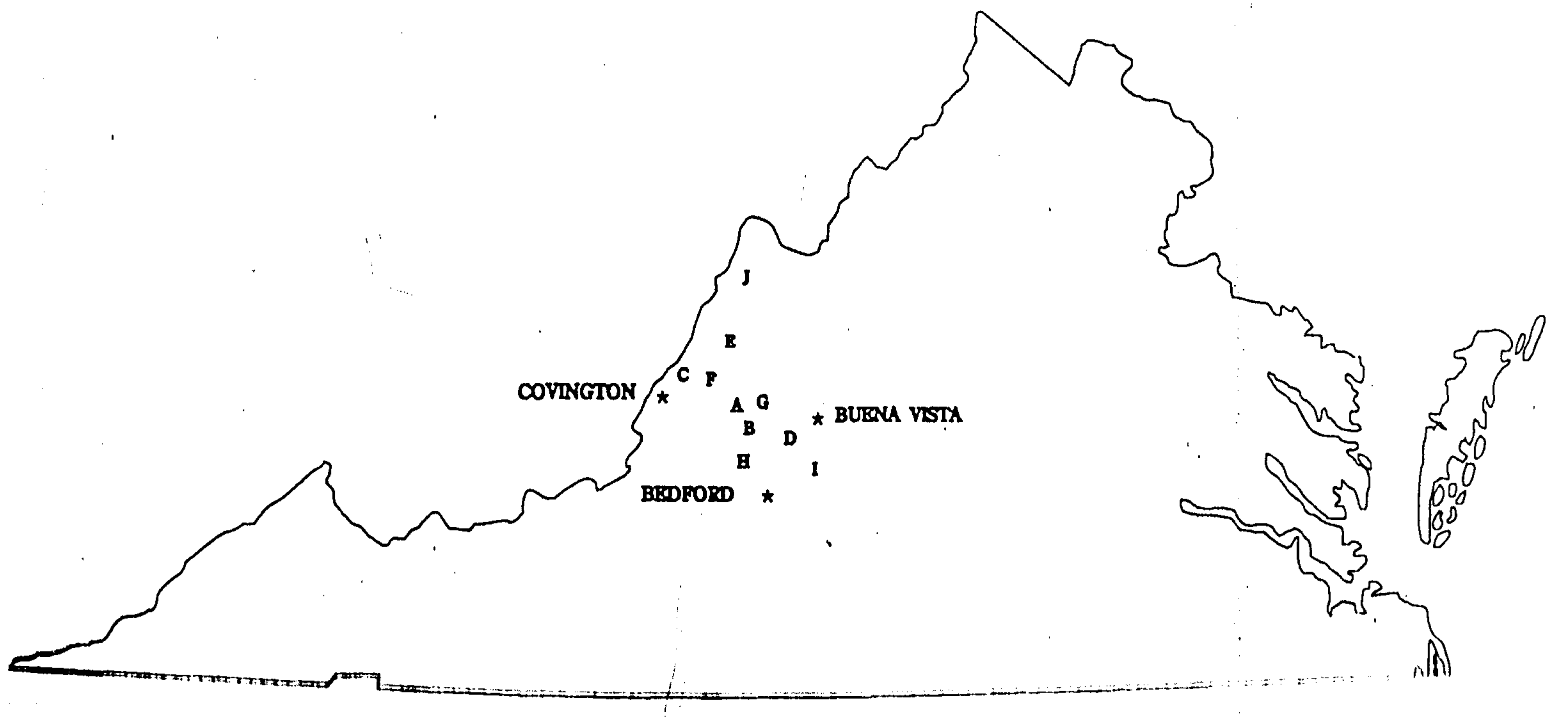


Figure 3. Study area locations.

Table 1. Summary of physical characteristics of the study tracts.

Tract	Ownership	size (acres)	Rainfall During Harvest	Soil Type	Average % Slope	Aspect
A	Industry	11.0	13.59 in. 3 months	silt loam and stoney loam (1)	43	west
B	Industry	15.7	11.53 in. 4 months	shaly silt loam (2)	33	north
C	Public	16.1	14.12 in. 4 months	sandy loam to loamy sand (3)	35	north-west
D	Private	20.8	12.02 in. 3 months	stoney, fine sandy loam (4)	21	north-west
E	Public	40.4	13.45 in. 4 months	sandy loam to loamy sand (3)	27	south-west
F	Public	18.0	6.84 in. 3 months	sandy clay loam silt loam (5)	29	south-east
G	Industry	19.8	22.65 in. 4 months	shaly silt loam (2)	37	east
H	Public	23.5	17.12 in. 3 months	stoney, fine sandy loam (6)	25	north-west
I	Private	39.0	22.70 in. 4 months	stoney, fine sandy loam (4)	28	north-west
J	Public	19.9	13.46 in. 3 months	shaly silt loam (7)	31	east

1/ Sequoia and Dekalb.
2/ Berks-Weikert.
3/ Leetonia.
4/ Edneytown.
5/ Landig-Berks.
6/ Edneytown-Peaks-Thurmond.
7/ Berks-Weikert-Rushtown.

Table 2. Summary of study-tract harvest characteristics.

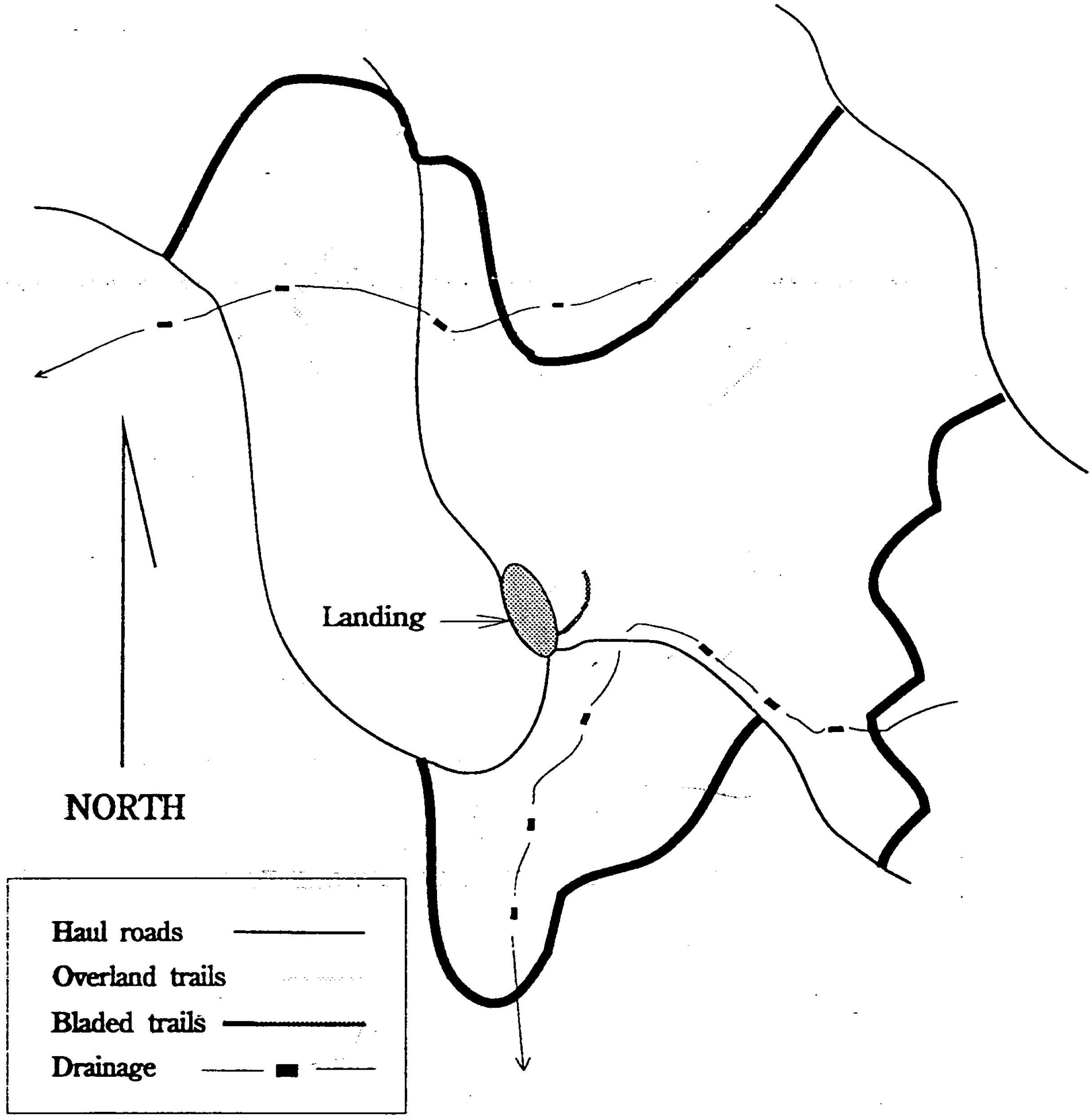
Tract	Season of Harvest	Skid Trail Type	Equip. (make/ model/tire size)	Skid Direction	Cubic Feet Harvested (per acre)
A	summer	overland	Timberjack 240E 23.1x26	15% uphill 85% down	2332
B	fall	overland	Timberjack 240E 23.1x26	96% uphill 4% down	3421
C	winter	overland	CAT 518 23.1x26	1% uphill 99% down	1509
D	spring	overland	Timberjack 230D 23.1x26	80% uphill 20% down	1734
E	summer	overland	John Deere 640 23.1x26	65% uphill 35% down	1602
F	winter	bladed/ overland	CAT 518 18.4x34	35% uphill 65% down	1702
G	summer	bladed	Timberjack 450 23.1x26	95% uphill 5% down	2266
H	spring	bladed/ overland	Timberjack 230/ 450 18.4x34	94% uphill 6% down	2293
I	summer	bladed	Cat 518 23.1x26	2% uphill 98% down	2301
J	spring	bladed	John Deere 18.4x34	92% uphill 8% down	1072

nearly 100 percent overland skid trails as seen on the map in Figure 4 (one short section of bladed skid trail was installed to the east of the landing). The boundaries of the tract were permanent roads on the east, south, and west, and rock cliffs on the north. The tract was logged during the period from July to September, 1988. Field data collection took place in late March, 1989. There was no growing season between harvest and measurement.

Analyses of the plot data indicated that 81 percent of the tract surface had been left undisturbed. Eight percent of this undisturbed area was covered with slash which impaired verification of its present surface condition. Twelve percent of the area fell into the slightly disturbed category. Only seven percent was in the severely disturbed category and less than one percent of the tract was in depression deposits. Three percent of the slightly and severely disturbed areas were judged to have been compacted. Thirteen percent of the undisturbed area fell into the non-soil sub-classification and provided a great deal of protection to the forest floor. Debris piles covered roughly 15 percent of the tract surface and were spread over all the disturbance classes.

Only 115.6 cubic yards of soil were moved during the logging operation; 96 cubic yards were attributed to landing construction and 19.6 were associated with installation of waterbars during tract closure.

Figure 5 shows the frequency of individual plot estimates of on-tract soil movement as calculated using the Universal Soil Loss Equation. This demonstrates the influence of a few troublesome spots on tract averages. One of the 121 estimates yielded a soil movement estimate of 158 tons/ac/yr. This plot was located on a skid



Scale 1" = 200'

Figure 4. Map of tract A.

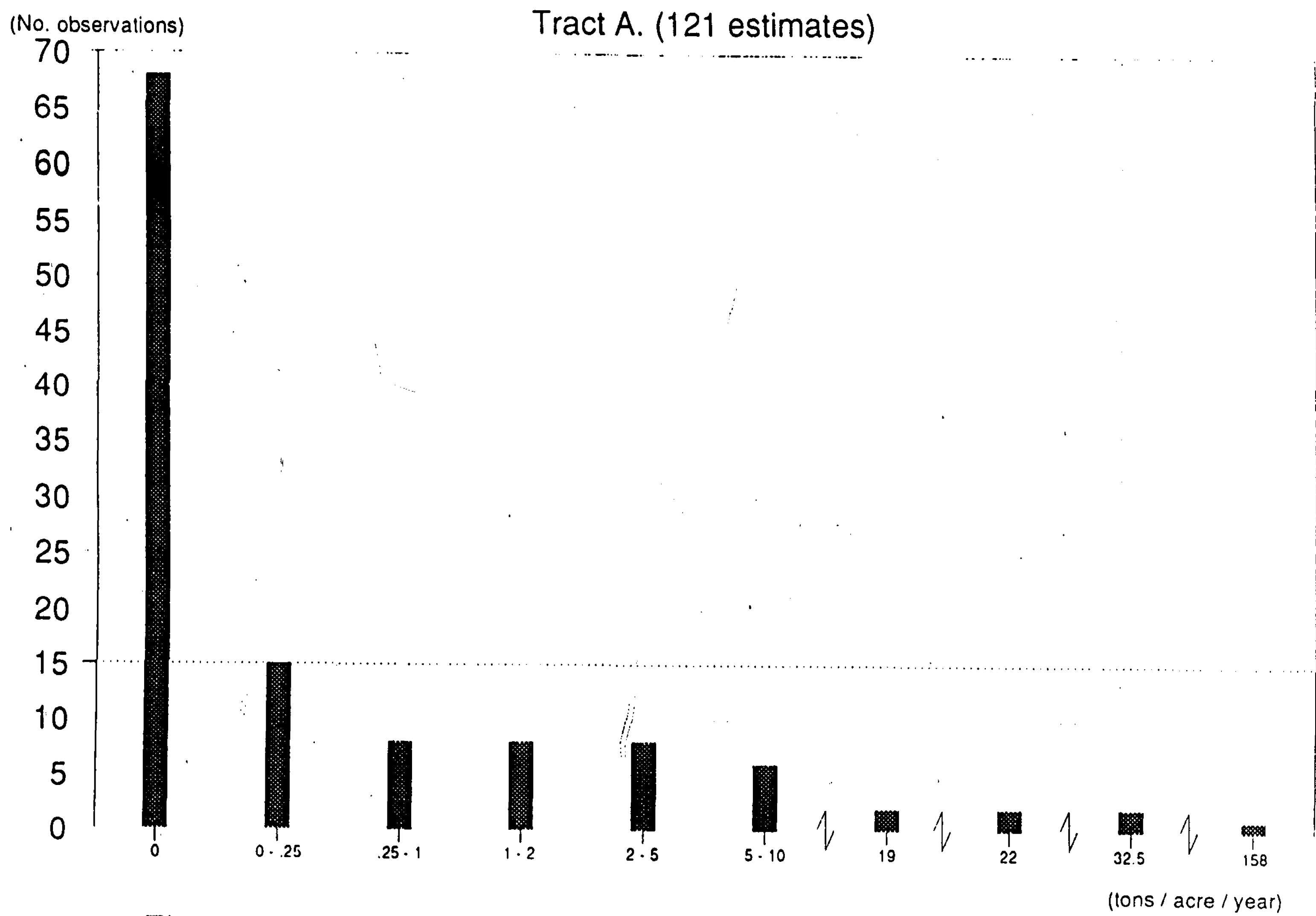


Figure 5. Frequency of potential soil movement estimates from the Universal Soil Los's Equation.

trail with a 50 percent slope. A small drainage ran across this trail, directly below the plot, permitting none of the soil from this point to be stored on-site. If slash had been deposited in this drainage, this estimate could have been cut in half. This is in conflict with traditional logging practices and the current BMP's which state that harvested tops and slash are to be removed from water drainages. (This practice dates back to guidelines written in the 1940's [VA Department of Forestry, 1989]). However, it appears that when slopes are this steep, slash within drainages may actually benefit water quality by reducing sedimentation. Two additional plots were projected to have soil movement of 32.5 tons/ac/yr each. These plots were also located on skid trails. However, adequate sediment barriers ensured that soil moving from these points would be retained on-site.

The average soil movement for this tract, taken as a strict arithmetic average, was 3.37 tons/acre/year. Soil movement in most instances did not necessarily mean soil entering streams, but referred to soil shifting from one point to another within the tract. Better tract closure on the two plots exhibiting the highest soil movement estimates, leaving them with virtually no soil movement potential, would have reduced this average to 2.10 tons/acre/year. Treating the five plots with the highest estimates in a similar manner would yield an average of 1.08 tons/acre/year.

Average mechanical strength differences for undisturbed, slightly disturbed, and slightly disturbed/compacted classes are shown in Figure 6. Small increases between averages of the undisturbed and slightly disturbed classes were found. Less than ten observations of the slightly disturbed/compacted class were taken. This class accounted for roughly two percent of the tract surface. The mechanical strength on the few spots encountered reached levels that would restrict root growth by 25 to 30 percent (Taylor

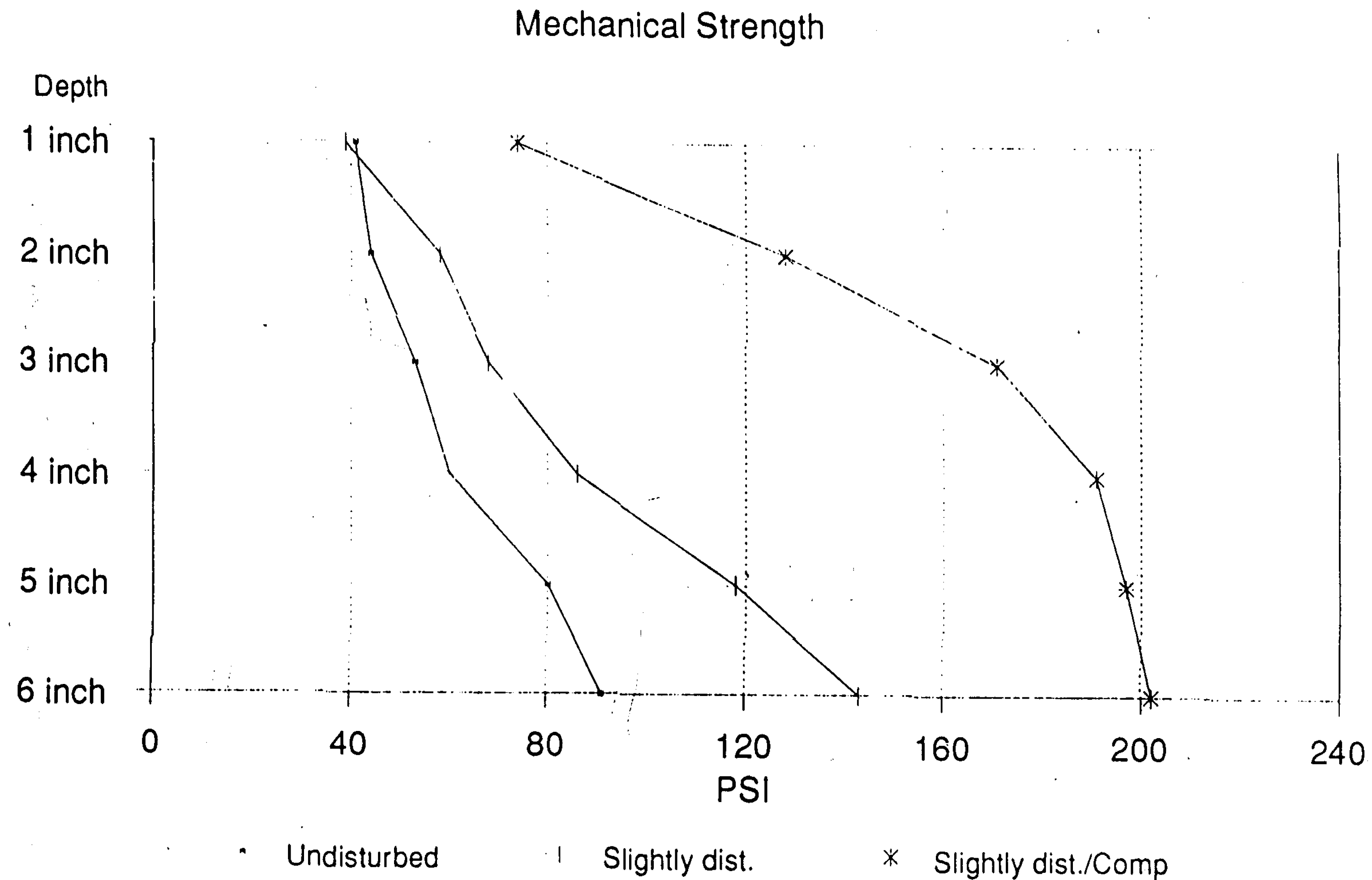


Figure 6. Average mechanical strength with depth on Tract A. (undisturbed, slightly disturbed, and slightly disturbed/ compacted).

and Gardner, 1963). But, this would not pose a serious loss of long term productivity.

Tract B

Tract B (15.7 acres) is located in Botetourt County and is also owned by forest industry. Management objectives were centered around hardwood pulp production. The tract was bounded on the north by ownership limits, and on the south by a permanent woods road with gated access. This road was used for skidding purposes, however, it was constructed prior to the harvest. There were no concentrated water drainages on this tract and a forested barrier existed between the western side of the tract and the closest permanent stream (Figure 7).

The tract was harvested between September and December, 1988 and the data was collected in early June, 1989. This provided approximately one-quarter of a growing season for development of herbaceous material and coppice regeneration. A Timberjack 240E, mounted on 23.1x26 tires, was used for skidding on this tract.

Analysis of the plot data indicated that 79 percent of the tract surface area remained undisturbed after the harvest. Twelve percent of this area was buried under debris piles. The slightly disturbed portion amounted to 14 percent of the surface area and only six percent was severely disturbed. Depression deposits covered roughly one percent of the area.

In the sub-categories, three percent was classified as compacted and 23 percent of the tract was covered with slash. Slash was used to bed the surface of the skid trails and had a noticeable effect on reducing surface disturbance. The soils were very

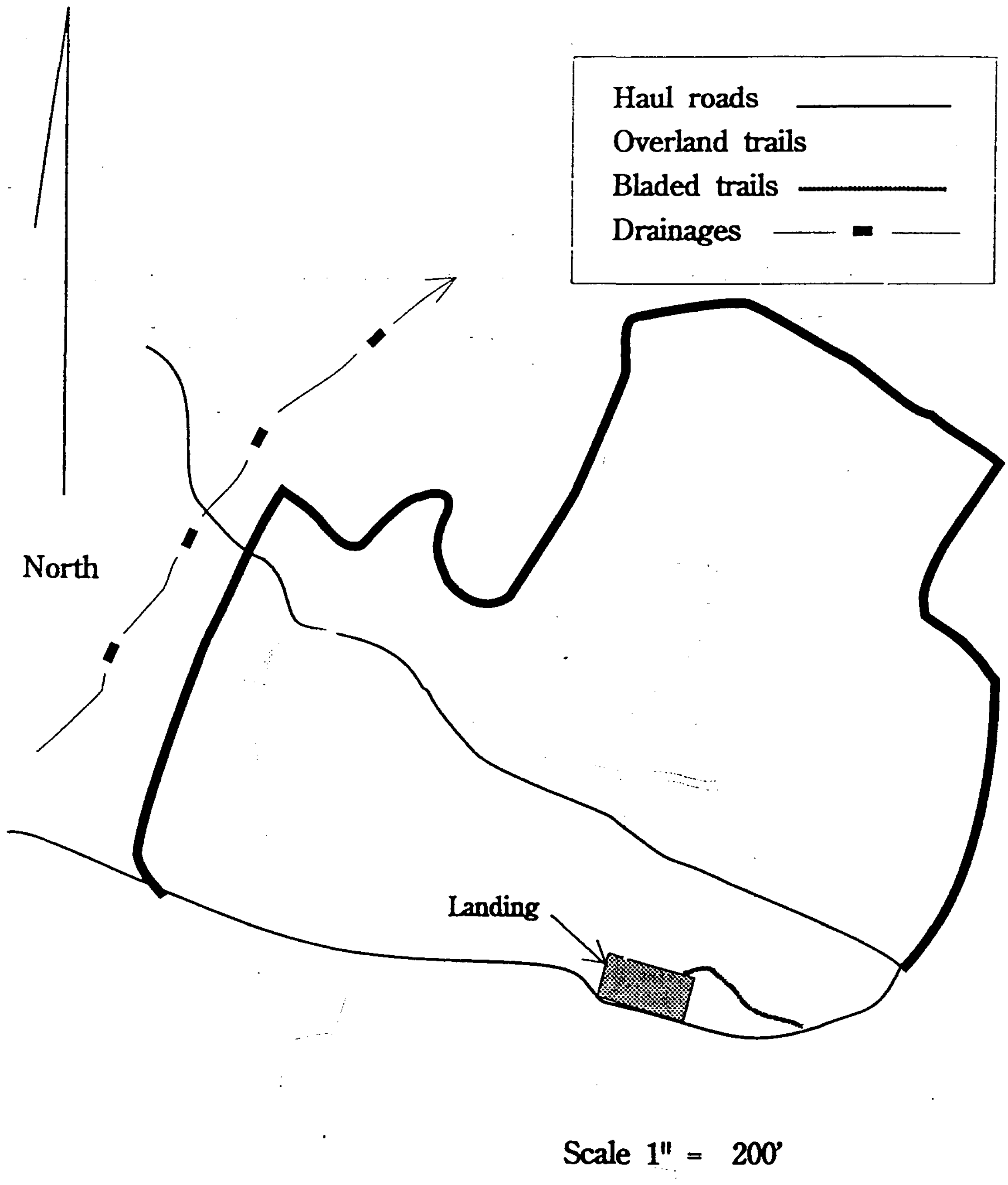


Figure 7. Map of tract B.

stoney. Nineteen percent of the tract surface fell into the non-soil class, the largest non-soil area for the ten study areas.

The total soil movement in earthworks was less for Tract B than for Tract A. Approximately 25 cubic yards of soil were moved for the installation of the landing, two cubic yards were moved while installing waterbars, and eight cubic yards were moved to provide skid trail access to the tract from a haul road.

The soil on Tract B was well drained, Berks-Weikert, shaly silt loam. These soils are generally formed from sandstone, siltstone, and shale. The large amount of rock fragments in the soil on tract B protected much of the surface from rutting, compaction, and surface deterioration during harvest.

Individual soil movement estimates, using the Universal Soil Loss Equation, for 154 plots are shown in Figure 8. Again, relatively few sample plots, yielding very high soil movement estimates, caused a noticeable upward shift in arithmetic average of 2.86 tons/acre/year. If the two highest estimates are excluded, the average drops to 2.21 tons/acre/year. Better closure on the five plots having the largest soil movement estimates, bringing them to no estimated soil movement, would have reduced the average to 1.92 tons/acre/year. The five highest estimates were observed to have a large percentage of bare soil, very little if any cover, and little to no on-site storage of sedimentation.

Average mechanical strength readings are shown in Figure 9. The slightly disturbed/compacted soil occupied less than two percent of the surface area and posed no serious threat to long term root extension. Noticeable differences between the averages seem to drop off after the fourth inch supporting that the most severe

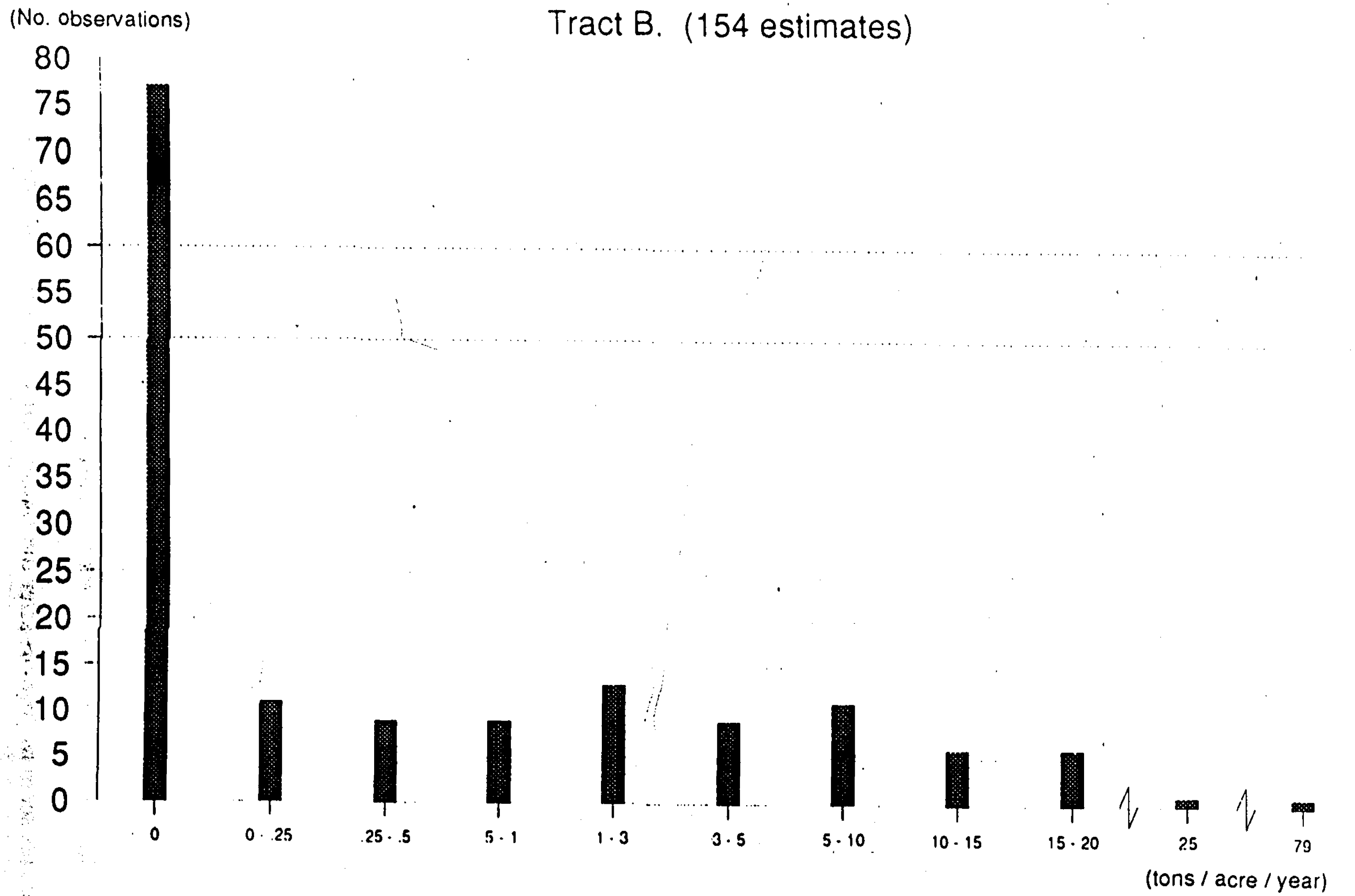


Figure 8. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

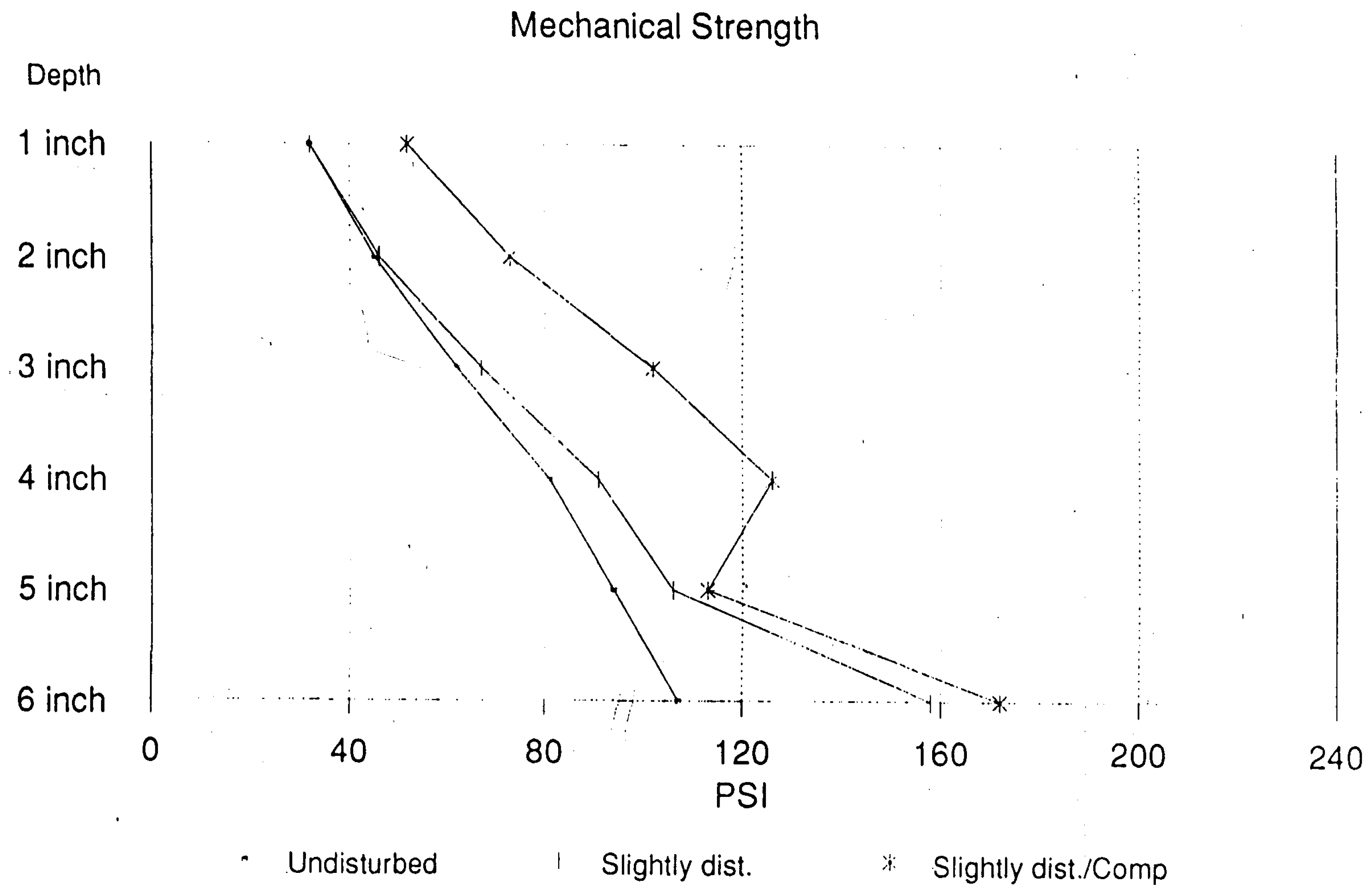


Figure 9. Average mechanical strength with depth on Tract B. (undisturbed, slightly disturbed, and slightly disturbed/ compacted).

compaction occurs within the upper 3.5 inches and decreases with depth (Burger et al., 1985).

Tract C

Tract C (16.1 acres), located in Alleghany County, is part of the Jefferson National Forest. It is managed primarily for timber production and wildlife. Tract boundaries consisted of a haul road on the northwest and sale boundaries on all other sides. The permanent road was constructed for several individual logging jobs in the area and was closed to vehicles after harvesting was completed. This tract did contain two ephemeral streams which came together at a point to the west of the landing (Figure 10). However, no serious problems were associated with them. A wildlife plot was left at the south central border of the tract through contractual agreement.

The skidder used to harvest this tract was a CAT 518 with 23.1x26 tires. The harvest took place between February and May, 1989. The field data collection was performed in early August. This allowed approximately one growing season to pass.

A more complex pattern of overland skid trails was used on this tract than on the two previous tracts, but the percent of undisturbed area following the harvest (79 percent) remained about the same. The percent of undisturbed area covered with debris piles (2 percent) was considerably less. Fifteen percent of the tract surface fell into the slightly disturbed category and six percent in the severely disturbed category. Less than 0.5 percent of the surface displayed depression deposits.

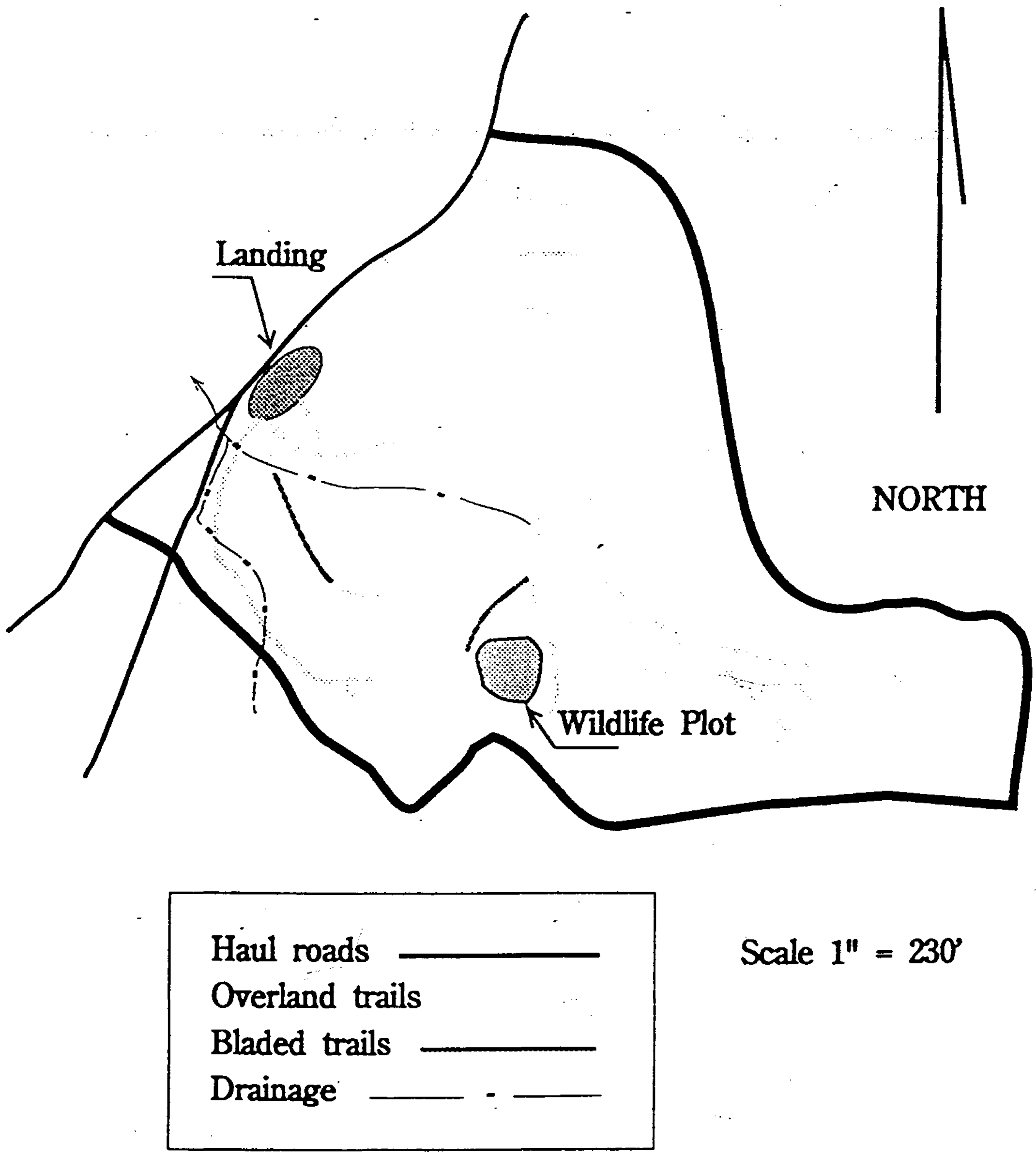


Figure 10. Map of tract C.

The percentage of the tract area falling into the sub-classifications of compaction (3 percent), and non-soil (15 percent) were approximately the same as for the two previous tracts. Debris piles, on the other hand, covered only six percent of the area. This figure is much less than the previous tracts and was the lowest amount of area existing in this class. This was assumed to be due to a combination of the tract stocking and the limbing procedures used during the logging operation.

Very little soil was moved in earthworks on this tract. Skidding was performed overland and the only soil movement was for the construction of the landing (23.7 cubic yards), waterbars (22 cubic yards), and a truck turnaround (13.5 cubic yards) for a total of approximately 60 cubic yards of soil relocation.

The Leetonia soil (ranging from a loamy sand to a sandy loam) on Tract C had several areas which were very stony. This soil was well drained on the southeasterly portion of the tract and moderately drained on the northwesterly face.

The histogram for the 77 soil movement estimates on Tract C (Figure 11) demonstrates the importance of tract closure. The maximum soil movement estimate on Tract C was 6.3 tons/acre/year with an arithmetic mean for this tract of 0.41 tons/acre/year. The average was re-calculated excluding the highest two and highest five plot estimates of soil movement yielding 0.27 tons/acre/year and 0.13 tons/acre/year, respectively, demonstrating the difference a small amount of additional job-closure effort could make. Treating the five plots with the highest estimates would have cut the average soil movement more than three fold. The fact that nearly 40 percent of

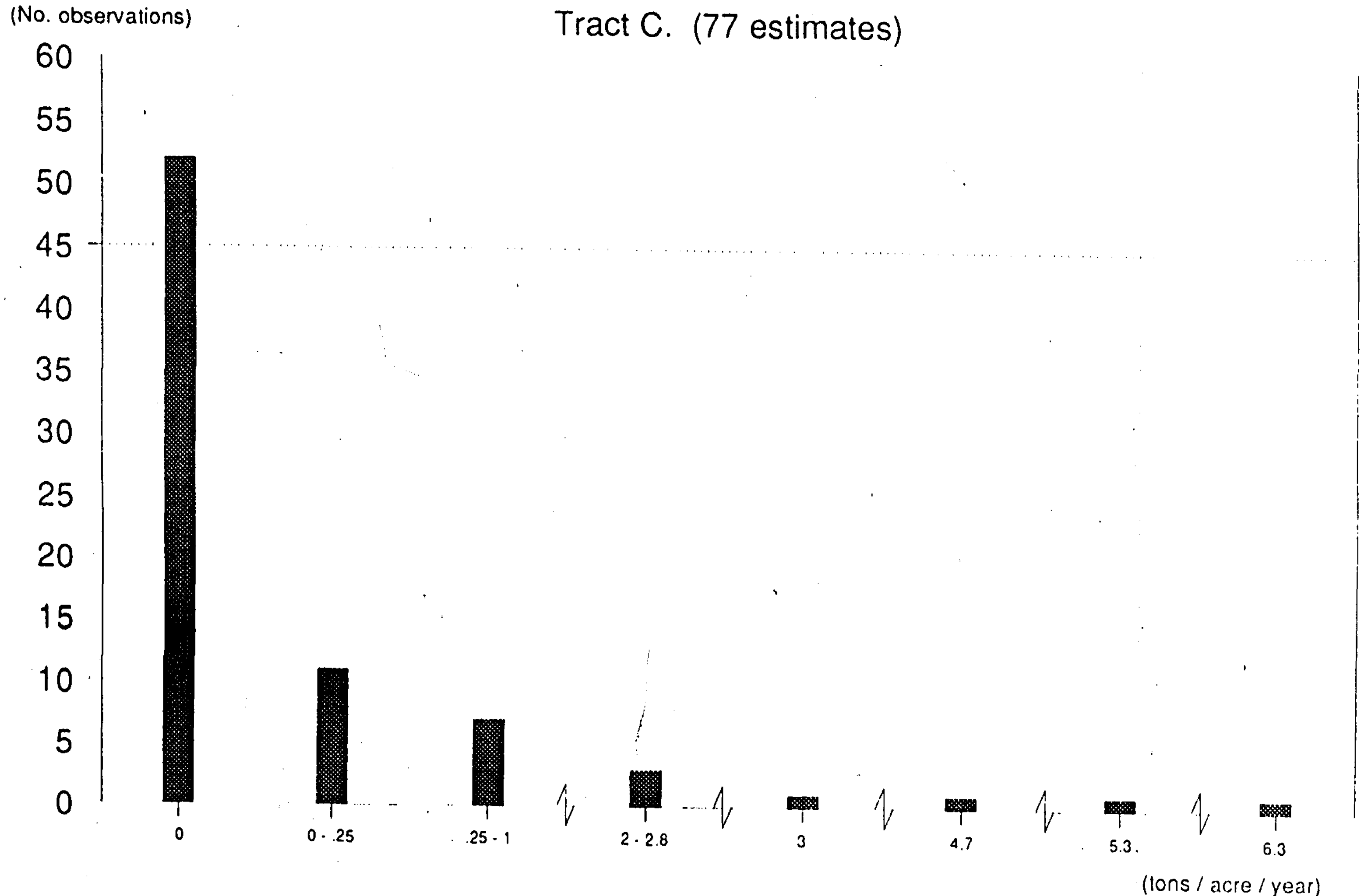


Figure 11. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

the total soil moved in earthwork was in waterbar construction, may be the reason these estimates are this low.

Less than 10 of the sample plots contained slightly disturbed/compacted soils. These accounted for two percent of the tract surface. Soil strength on these sites was increased to levels described by Graecen and Sands (1980) where root growth is considerably reduced (Figure 12).

Tract D

Tract D (65 acres) lies in Rockbridge County and is a privately owned woodlot managed primarily for its economic value. The timber was purchased by forest industry. They assisted in establishing the boundaries and sale layout. Tract D adjoined the Jefferson National Forest on the south and southwest, and was bound by the sale boundary to the east, and a ridge to the north.

The 65 acre tract consisted of two sections, and timber from each was skidded to a separate landing. The study area (Section 1, Figure 13) contained 20.8 acres on an average slope of 21 percent, the least for all study areas. The landing location (landing #1, Figure 13) was established by an industry forester, while the skid patterns were determined by the logger. The skidding was again overland with limited blading to allow access to the landing. A Timberjack 230D skidder on 23.1x26 tires was used. The harvest took place between February and April, 1989 and field data collection followed in late August.

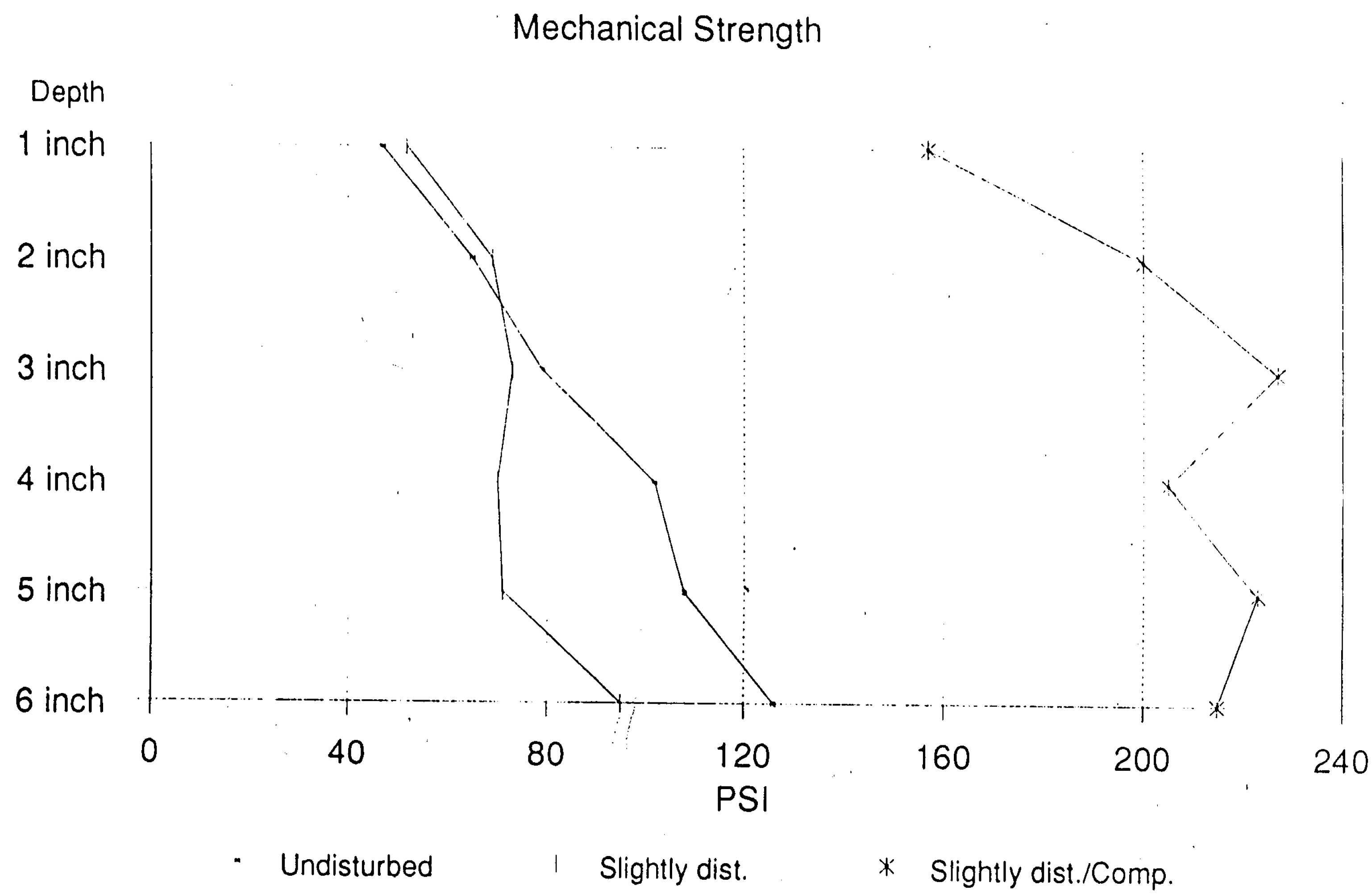


Figure 12. Average mechanical strength with depth on Tract C. (undisturbed, slightly disturbed and slightly disturbed/ compacted).

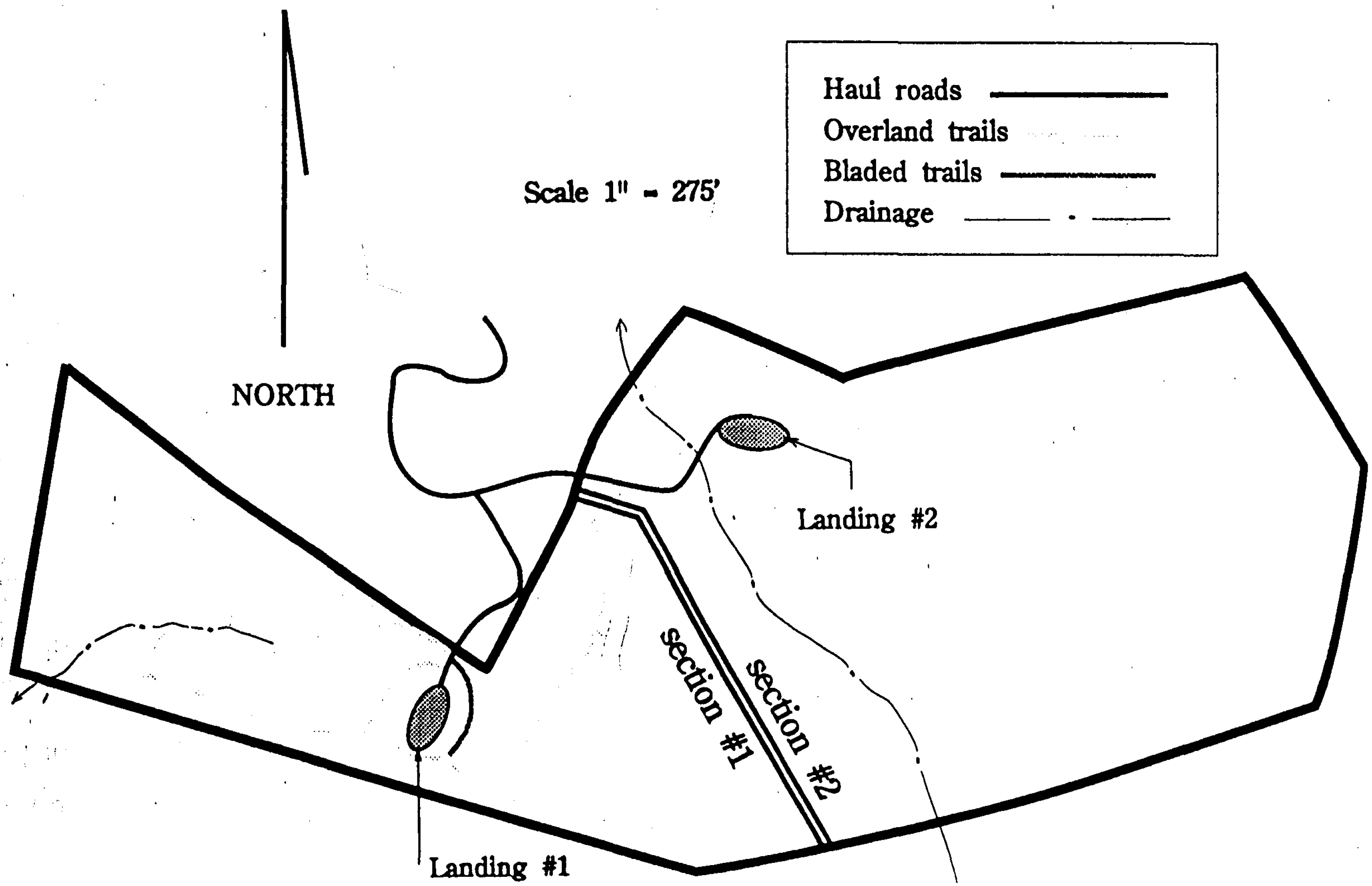


Figure 13. Map of tract D.

The plot data indicated that roughly 73 percent of the tract remained undisturbed after harvest, 15 percent was slightly disturbed, and 10 percent was severely disturbed. The increase in the severely disturbed category with respect to the tracts discussed previously may have been a result of high precipitation levels and fine textured soil. Despite the amount of rainfall during and after the harvest, only one percent of the tract surface was recorded as depression deposits. Within the sub-categories, eight percent of the tract area was estimated to be compacted, three percent was non-soil, and 15 percent was covered by debris piles.

Engineered earthworks resulted in a larger amount of soil volume being moved (432 cubic yards) than for the previously mentioned tracts. This was primarily due to haul road construction (402 cubic yards) specifically for this harvest. Additional earth was moved in constructing the landing (18 cubic yards) and a truck turnaround (11 cubic yards). No earth was moved to construct waterbars.

Soils on Tract D are classified as Edneytown series by the Soil Conservation Service. These soils are described as being fine sandy loam and stoney, fine sandy loam. The tract was moderately well-drained with some areas being poorly drained. Logging this tract in a drier period could have reduced soil disturbance considerably.

A histogram of the 97 soil movement estimates, using the Universal Soil Loss Equation again indicates a very low soil erosion risk of 0.37 tons/acre/year despite the lack of waterbars on the tract (Figure 14). The average would have been 0.27 tons/acre/year if the two highest plots had received additional treatment and 0.17 tons/acre/year had the worst five plots been treated. It is also possible that these estimates would have increased with the installation of waterbars.

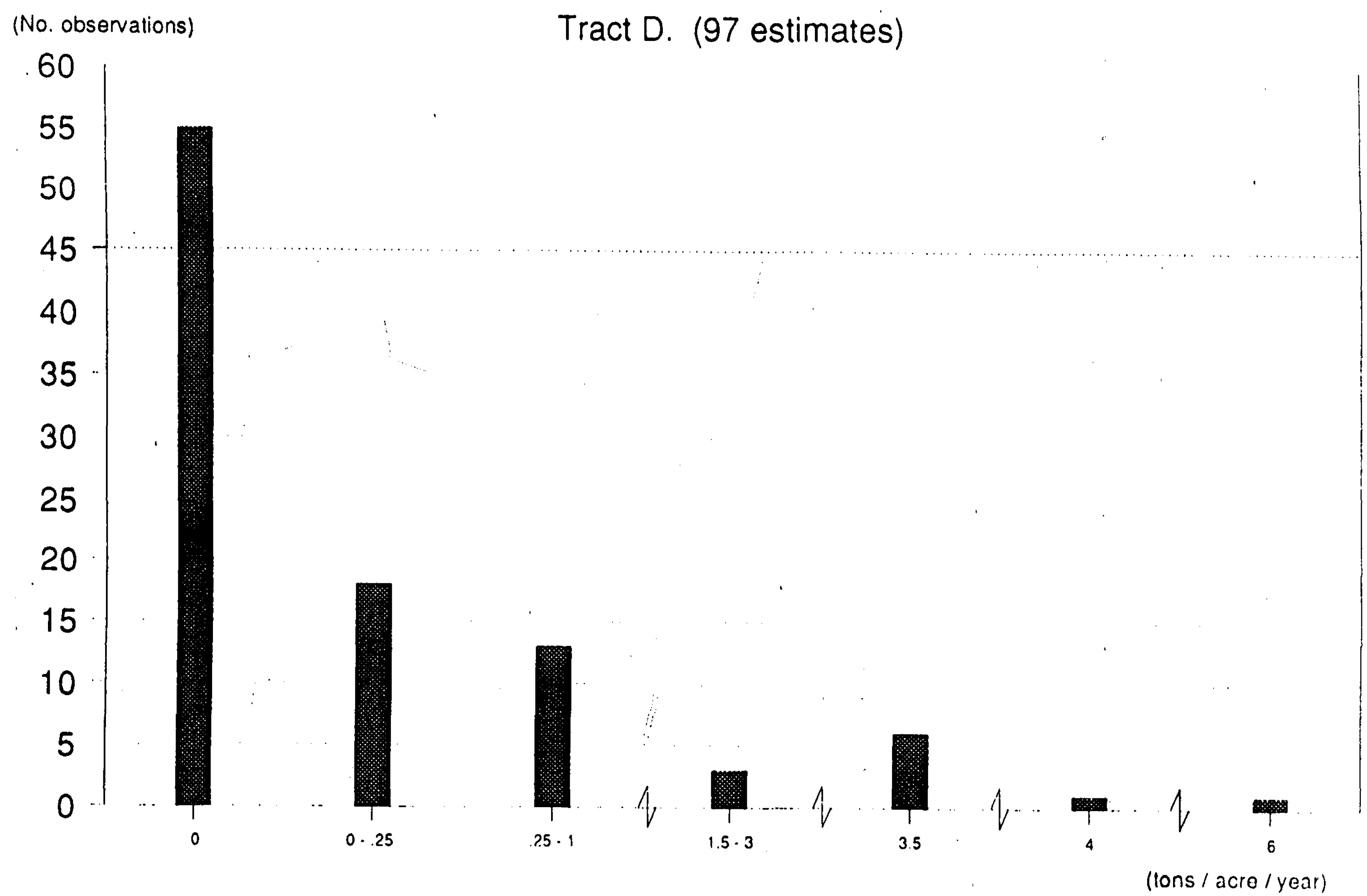


Figure 14. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

Soil mechanical strength averages are shown in Figure 15. There was a drop in average soil strength at the fourth inch for slightly disturbed/compacted areas. This is not characteristic of the undisturbed plots. The soil structure may have had a hard pan which was more resistant to compaction. Five percent of the tract was in this category, the largest for any of the study tracts.

Tract E

Tract E (40.4 acres), located in Bath County, is managed by the U.S. Forest Service for timber production and wildlife. Boundaries of this sale area were the painted borders within the larger boundaries of the National Forest. As on Tract C, a wildlife plot was left through contractual agreement. The tract was harvested between June and September, 1988 using a John Deere 640 skidder with 21.3x26 tires. Data collection followed in late June of 1989. This tract had the longest elapsed time between the harvest completion date and the field data collection, providing adequate time for vegetative regeneration and site healing. Revegetation was partly responsible for the low erosion risk estimate for this tract.

Summarizing the sample points installed on the tract, 81 percent of the total area was included in the undisturbed category, four percent of which was covered with debris piles. Eleven percent was considered slightly disturbed, eight percent was severely disturbed, and less than 0.5 percent was found to have depression deposits.

Four percent of the tract was estimated to have been compacted, and a total of 24 percent of the entire tract was under debris piles. This was assumed to be a function of the limbing procedures at the stump since stocking of this tract was the lowest of any

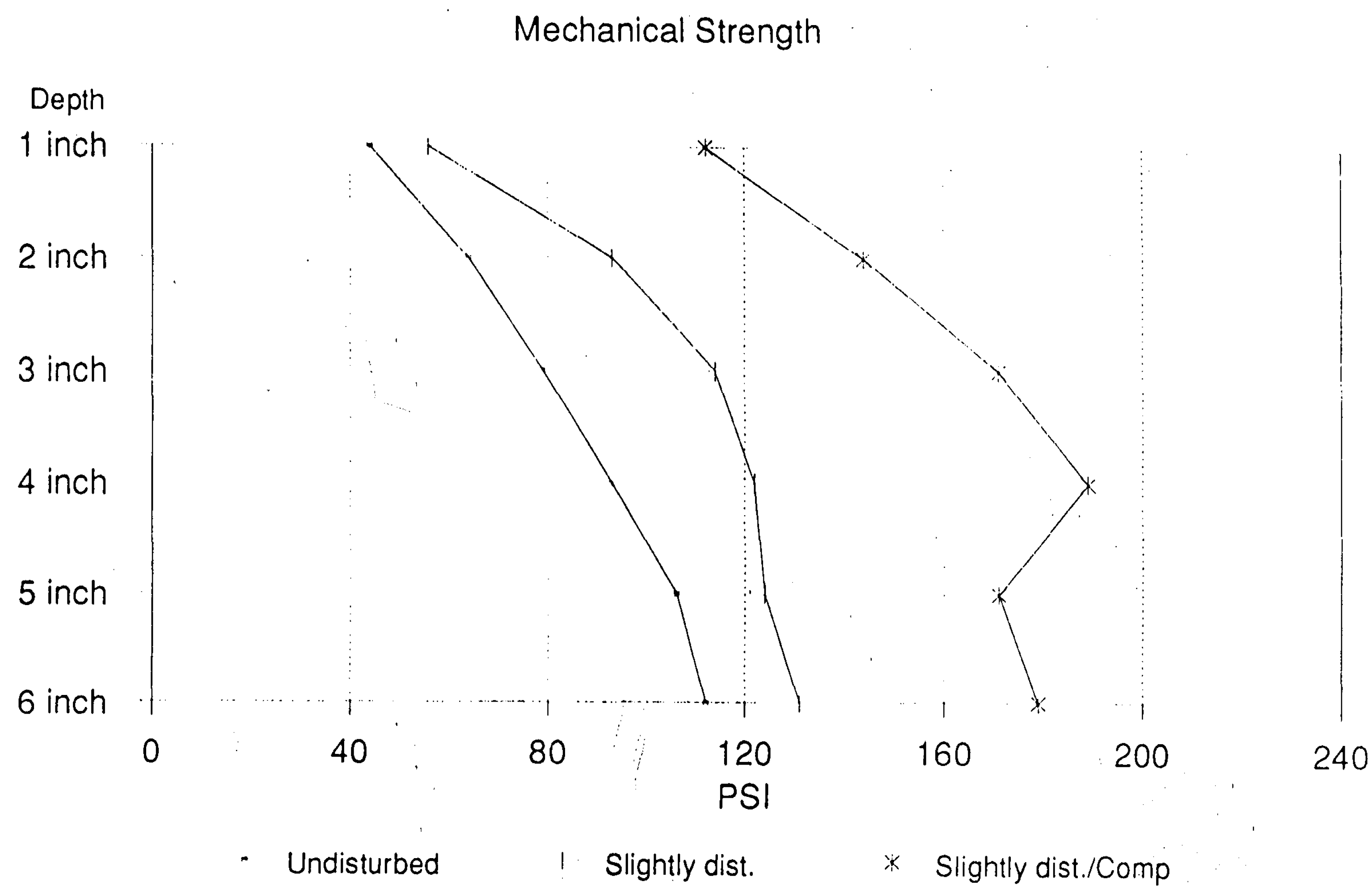


Figure 15. Average mechanical strength with depth on Tract D. (undisturbed, slightly disturbed, and slightly disturbed/ compacted).

of the study areas. Rock outcrops and stumps resulted in three percent of the undisturbed area estimated as non-soil.

The skid trails were all overland with the exception of the skidding which took place along the haul road passing through the center of the tract (Figure 16). This road served two landings, one at the haul road entrance to the tract and the other at a centrally located point within the tract. The haul road was established specifically for this harvest and resulted in 880 of the 1094 cubic yards of earth moved during the harvesting operation. The landing and waterbars accounted for the remaining soil volumes moved with 204 and 10 cubic yards respectively.

The soils on Tract E were of the Leetonia series, the same as those on Tract C. A major difference in non-soil (15 percent for Tract C verses 3 percent for Tract E) was found. The Leetonia series, characterized as loamy sand to sandy loam, is of sandstone derivation.

The histogram of the potential soil movement from the 135 point estimates (Figure 17) shows a fairly low risk of erosion as a result of a high degree of job closure and favorable harvesting conditions (dry weather, well protected drainages, and plenty of slash to filter soil sedimentation). This average was 0.21 tons/acre/year; the lowest for all study areas. Like most of the other tracts studied, the average would have been reduced by approximately one-half if the two highest soil movement points had received further treatment during job closure.

Average mechanical strength readings are illustrated by depth for Tract E in Figure 18. These readings were more uniform than other study areas; the slightly disturbed/compacted averages were not much different than those of slightly disturbed

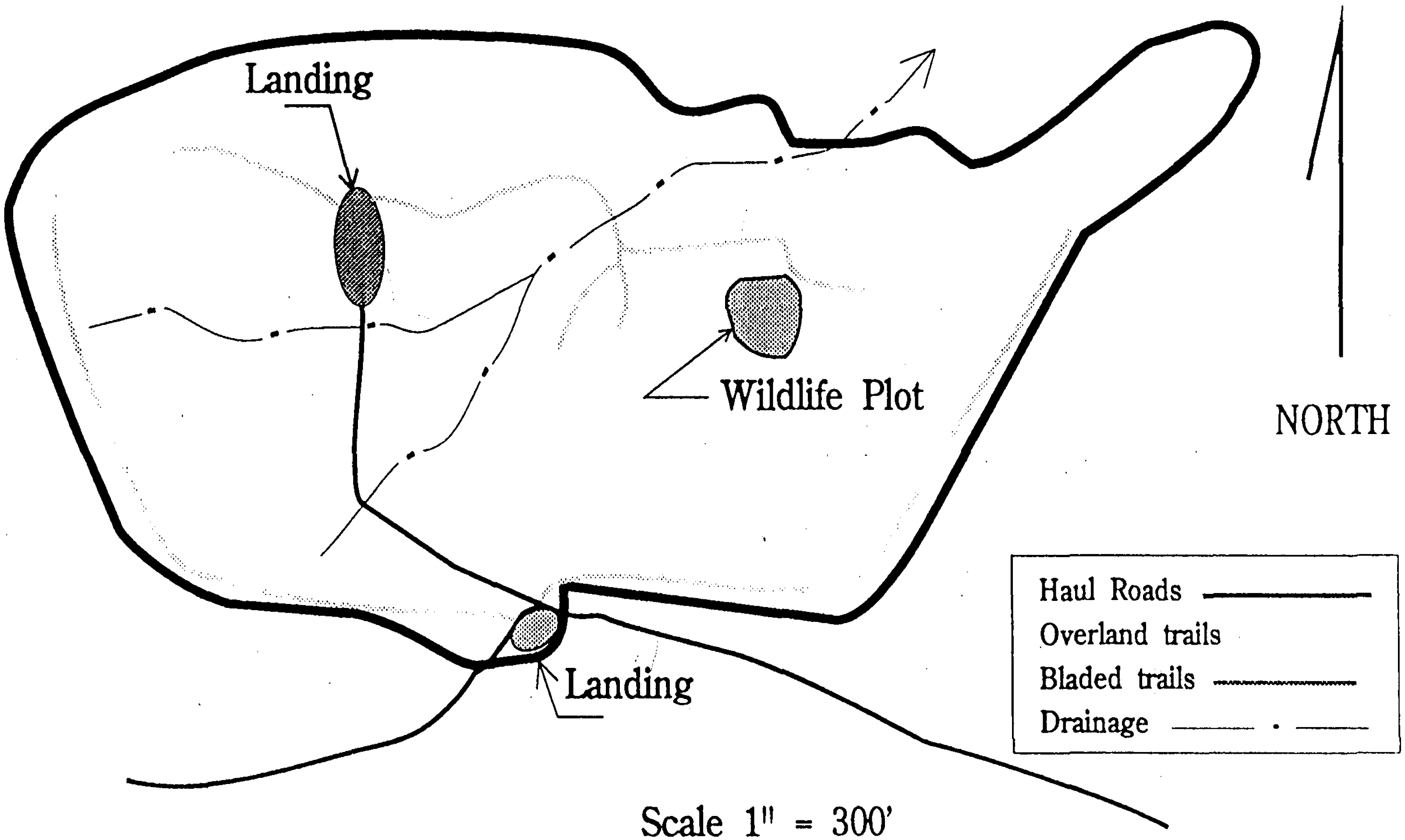


Figure 16. Map of tract E.

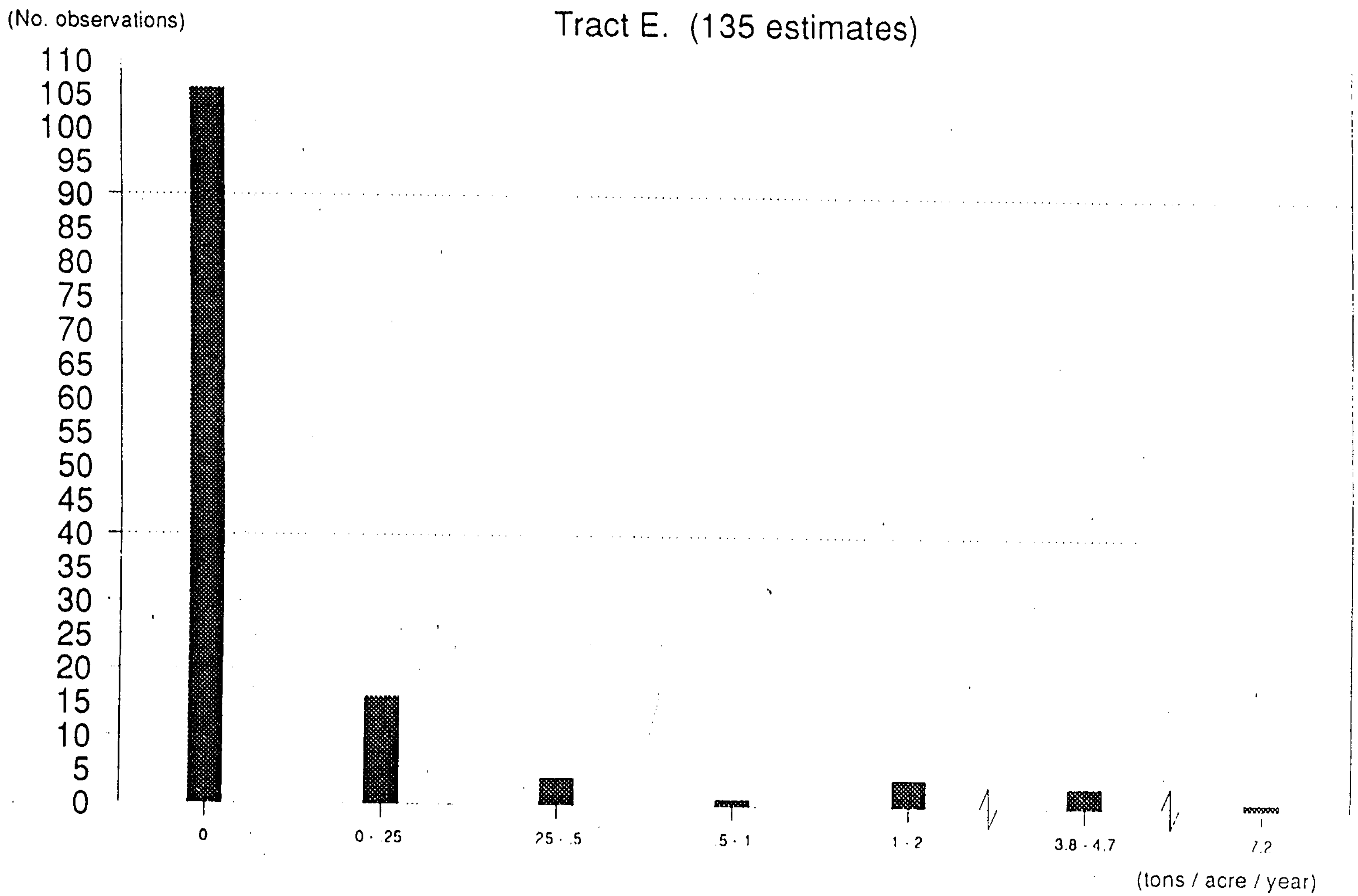


Figure 17. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

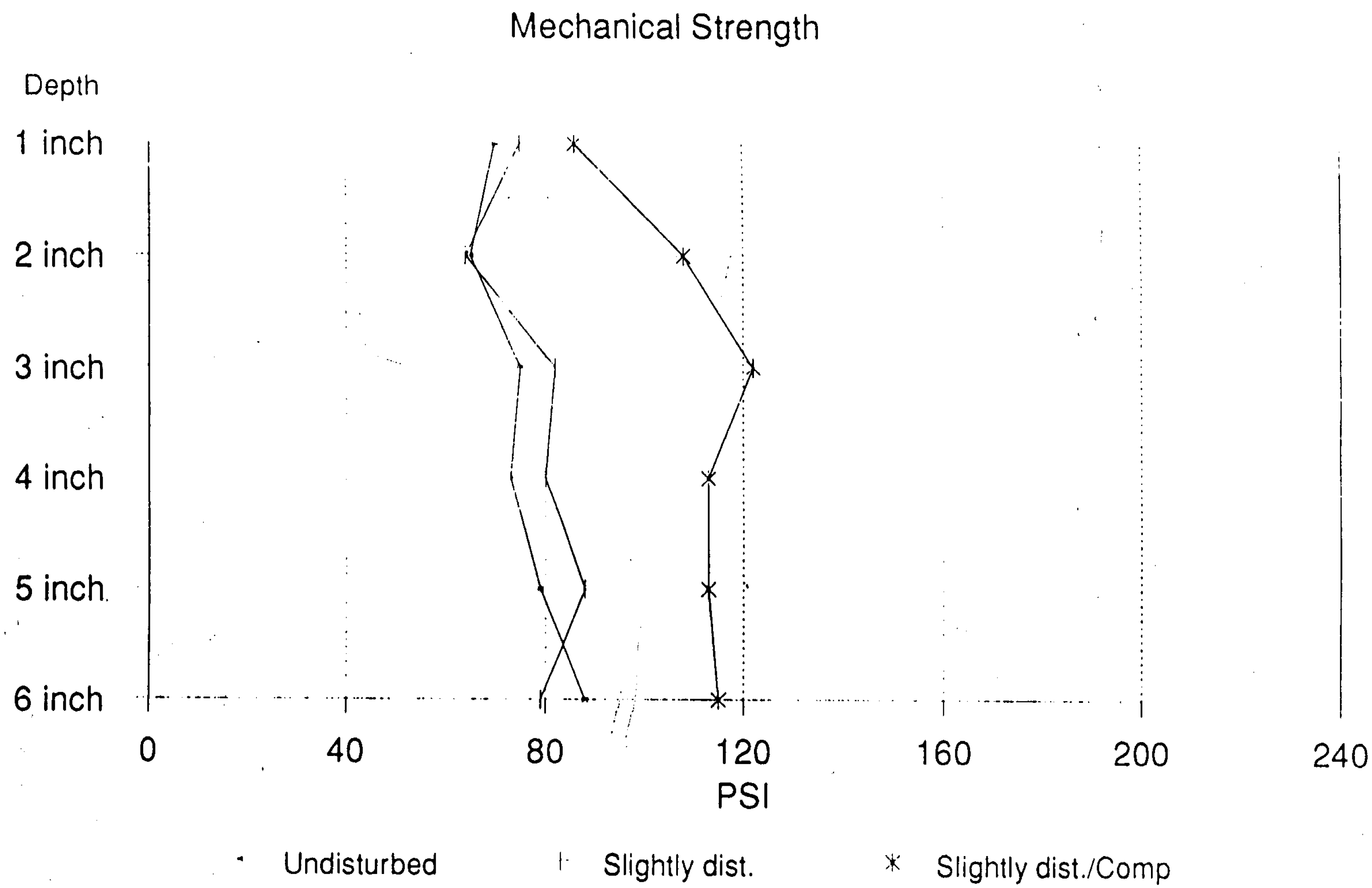


Figure 18. Average mechanical strength with depth on Tract E. (undisturbed, slightly disturbed, and slightly disturbed/ compacted).

and undisturbed. The highest soil strength average for the slightly disturbed/compacted class (at the third inch) was roughly 120 psi. The rate of root growth will be less at this soil strength than at 80 psi (the approximate average for the undisturbed and slightly disturbed classes); however, it will not pose a long term threat to decreased site productivity.

Tract F

Tract F (18.0 acres) is located in Alleghany County and lies on the Jefferson National Forest. It is managed for timber production and wildlife by the U.S. Forest Service. This tract, like others in the area, had several cutting units located on one temporary haul road which was to be gated after harvesting was completed. The area was harvested from January to March, 1989, and visited for data collection in July, 1989. A CAT 518 skidder with 18.4x34 tires was used for skidding operations on slopes averaging 29 percent. An average of 2.2 inches of rain fell each month during the harvesting period making it the driest harvesting period of all the tracts studied.

Overland skidding was used wherever possible on this tract. Bladed skid trails were installed at three locations on very steep slopes which blocked access to portions of the tract (Figure 19). None of these isolated sections joined the landing. The bladed trail sections accounted for 678 of the 684 cubic yards of soil moved during the harvest.

In summarizing data from the field plots, 75 percent of the tract was left in an undisturbed condition, 72 percent of which was visible and three percent was under dense piles of slash. The slightly disturbed portion was similar to Tracts A and E at 11

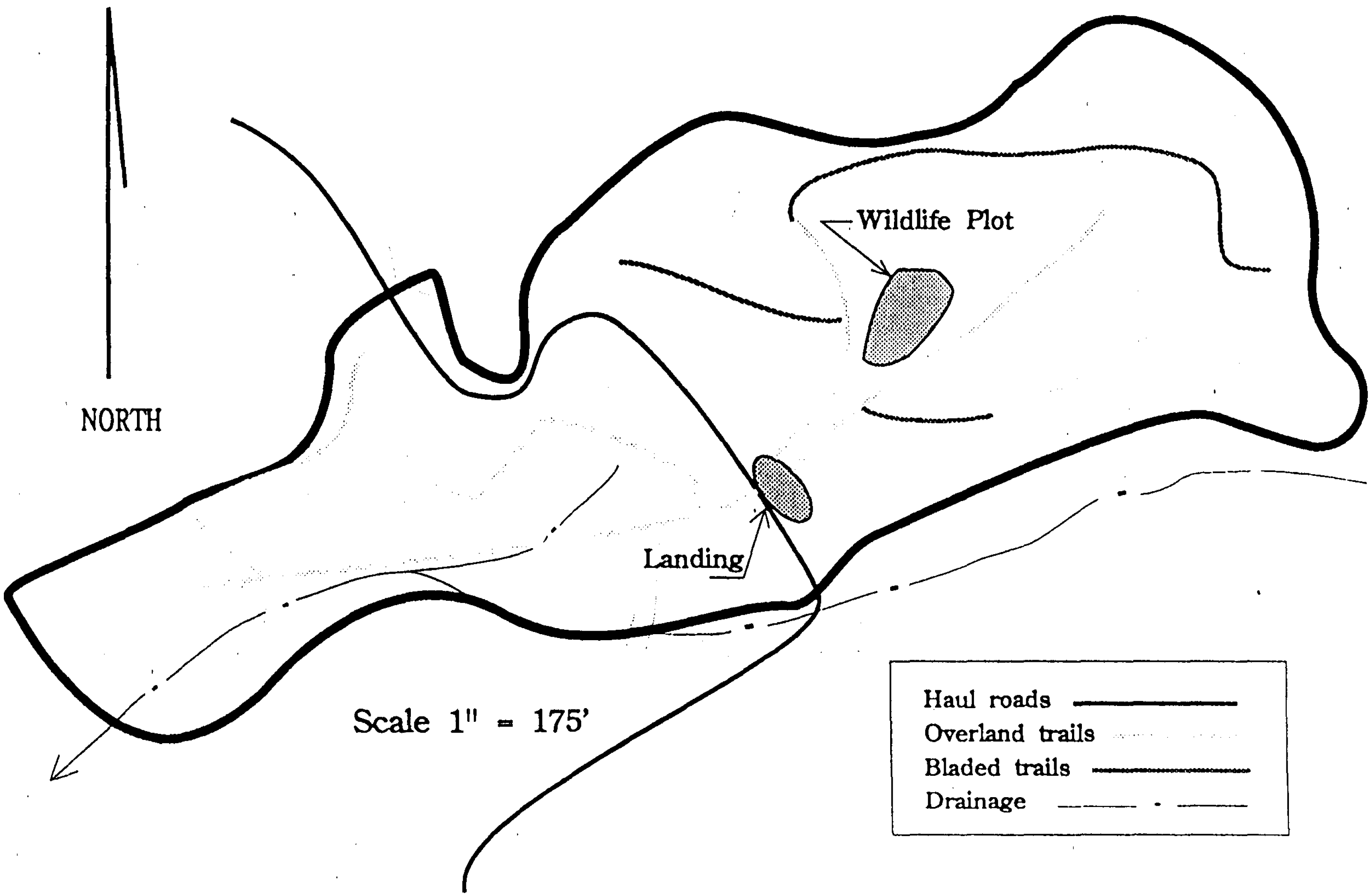


Figure 19. Map of tract F.

percent, however, 14 percent fell in the severely disturbed class as a result of bladed skid trails. Less than 0.5 percent of the tract displayed depression deposits.

Three percent of the total tract area (all within the slightly disturbed and severely disturbed categories) was visibly compacted. Fourteen percent of the tract was classified as non-soil (i.e., stumps or rock outcrops). Eleven percent of the total tract surface was covered with debris piles.

These soils are of the Landig-Berks series, a sandy-clay loam and silt loam, derived from sandstone and shale. The presence of sandstone was particularly noticeable in some surface areas. This surface rock offered protection from compaction during the harvest and from erosion after the harvest.

A histogram of the 84 potential soil movement estimates is shown in Figure 20. The average soil movement risk for Tract F was 1.08 tons/acre/year. Unlike the other tracts, no "hot spots" of unusually high soil movement were found. A good job closure had been done, but the spotty catch of grass seed resulted in a wide spread erosion risk.

Average soil mechanical strength readings for Tract F show little difference between undisturbed and slightly disturbed areas (Figure 21). Less than 10 samples fell into the slightly disturbed/compacted class. The compacted area accounted for less than four percent of the total tract area. This soil strength (200 to 236 psi) is less than that required to reduce root growth potential by 70 percent (Taylor and Gardner, 1963), although the rate of root growth will be reduced as a result of the increased soil strength.

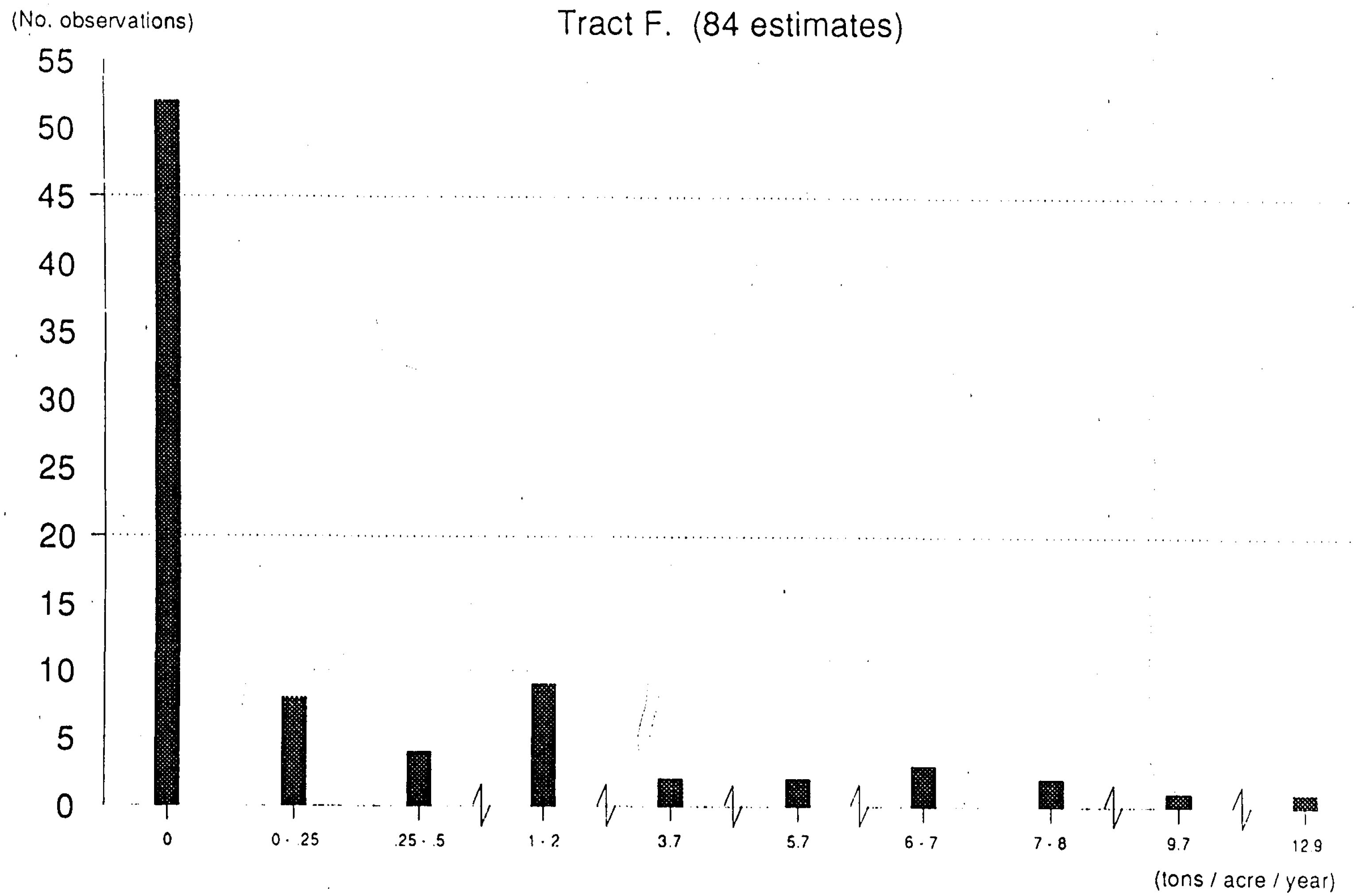


Figure 20. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

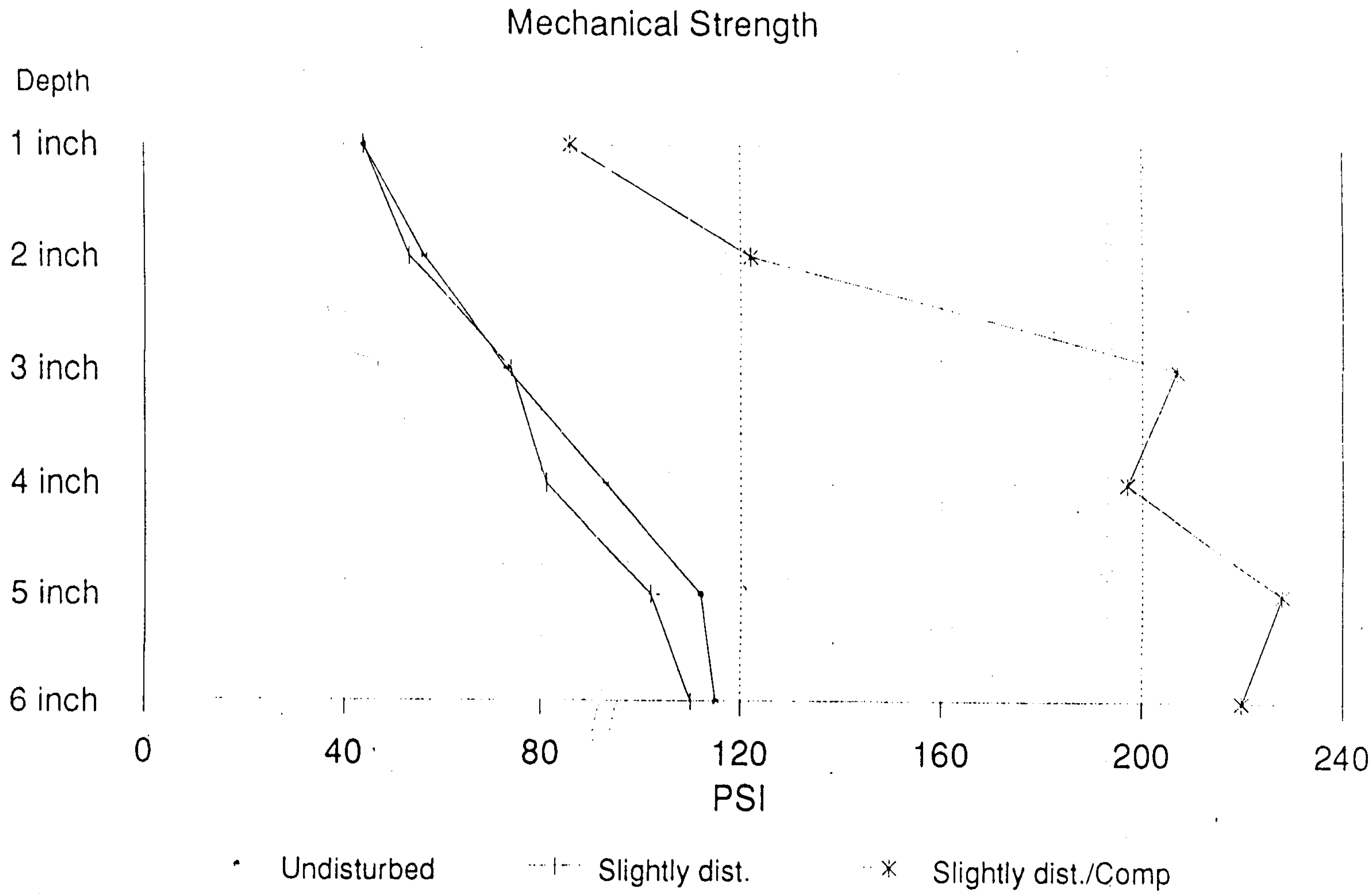


Figure 21. Average mechanical strength with depth on Tract F. (undisturbed, slightly disturbed, and slightly disturbed/ compacted).

Tract G

Tract G (19.8 acres) is located in Botetourt County, owned by forest industry, and managed for pulpwood production. The tract was harvested between May and August, 1989. Data collection followed approximately two weeks after harvest. The harvest was performed using a Timberjack 450 skidder on 23.1x26 tires.

Tract G was one of the steepest tracts in the study (37 percent average slope) and had the largest volume of soil displaced of all tracts in the study. The shape of the tract (a narrow strip following the contours) necessitated an extensive network of bladed skid trails (Figure 22). Trail construction resulted in the movement of 2128 cubic yards of earth. Less earth was moved in the construction of the landing (10 cubic yards) and waterbars (4 cubic yards) than on many other tracts.

The same logger cut Tracts B and G. Tract B was nearly as steep as Tract G, but the tract shape allowed more flexibility in harvesting which resulted substantially less earth moved.

All skid trails (but one) were laid out by an industrial forester. One skid trail was added by the logger after partial completion of the harvest. Haul roads were established prior to the sale and maintained in satisfactory condition throughout the harvest period. This tract was bounded by the haul road on the southeast. The northwest edge consisted of rock cliffs and unmerchantable timber.

The analysis of data from the sample plots found that 74 percent of the tract surface remained undisturbed after harvesting; four percent of which was under dense

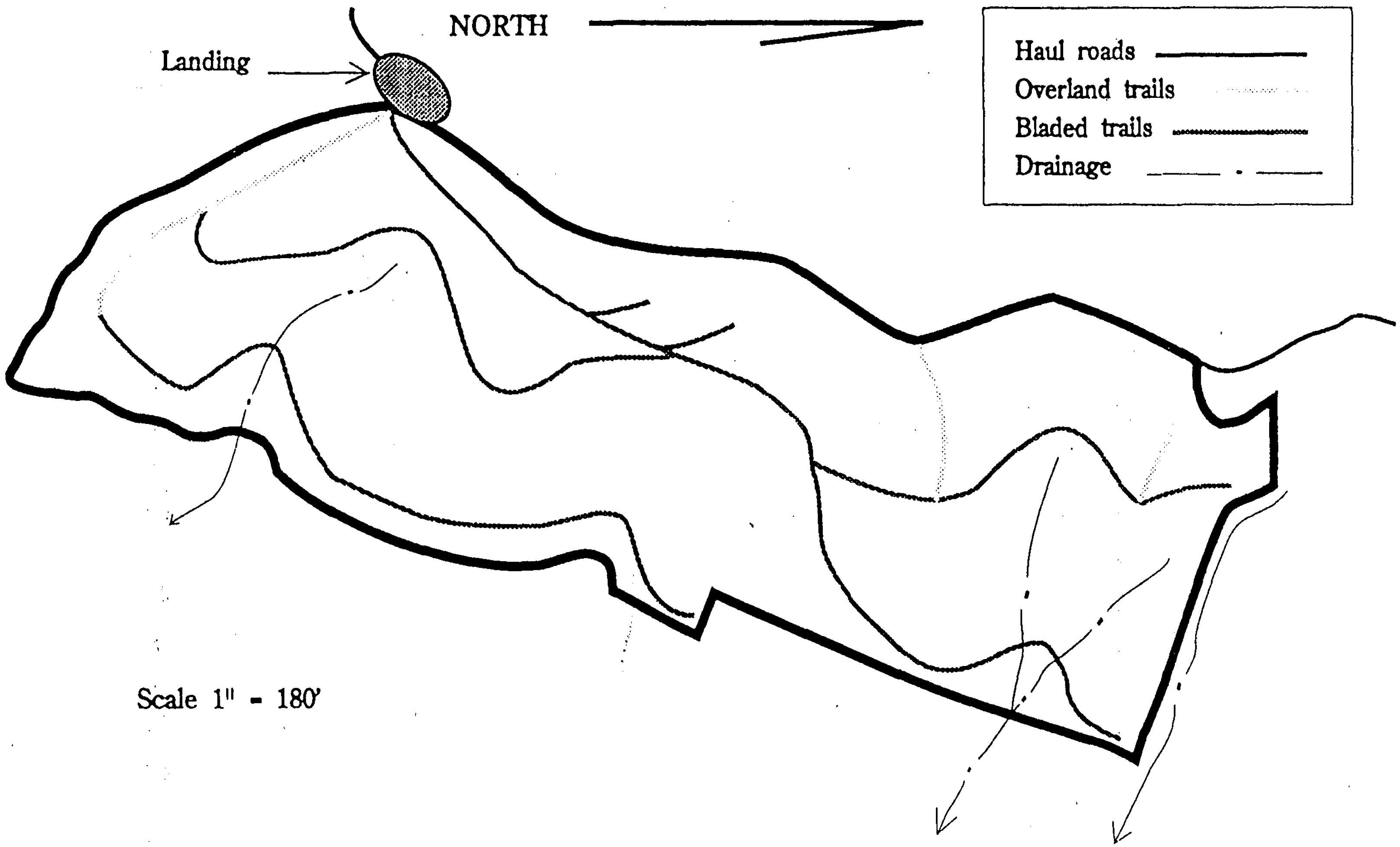


Figure 22. Map of tract G.

debris piles. Roughly 14 percent was categorized as slightly disturbed and 12 percent was categorized as severely disturbed. In the sub-classifications, three percent was considered compacted, another three percent was non-soil, and 31 percent of the total tract surface was covered with debris piles.

The soils were classified by the Soil Conservation Service as a Berks-Weikert series. These soils originate from sandstone, siltstone, and shale; on slopes of this nature they are well drained. The texture is described as shaly silt loam.

Thirty-eight point estimates of potential soil movement were taken and are shown in Figure 23. The arithmetic average of these samples was 2.94 tons/acre/year. As before, a relatively low percentage of plots contributed greatly to this average. If additional closure effort had been concentrated on the two worst areas, this average would have decreased by nearly one ton/acre/year. Treating the five plots with the largest soil movement estimates would have dropped this average to 0.66 tons/acre/year, almost a 4.5 fold reduction.

Soil mechanical strength readings from Tract G were not obtained because of personnel shortages. Since skidding was restricted to bladed skid trails, compaction would have been difficult to distinguish from the increase in soil mechanical strength associated with sub-soil exposure.

Tract H

Tract H (23.5 acres) is located in Botetourt County on the Jefferson National Forest and managed by the U.S. Forest Service for timber production and wildlife.

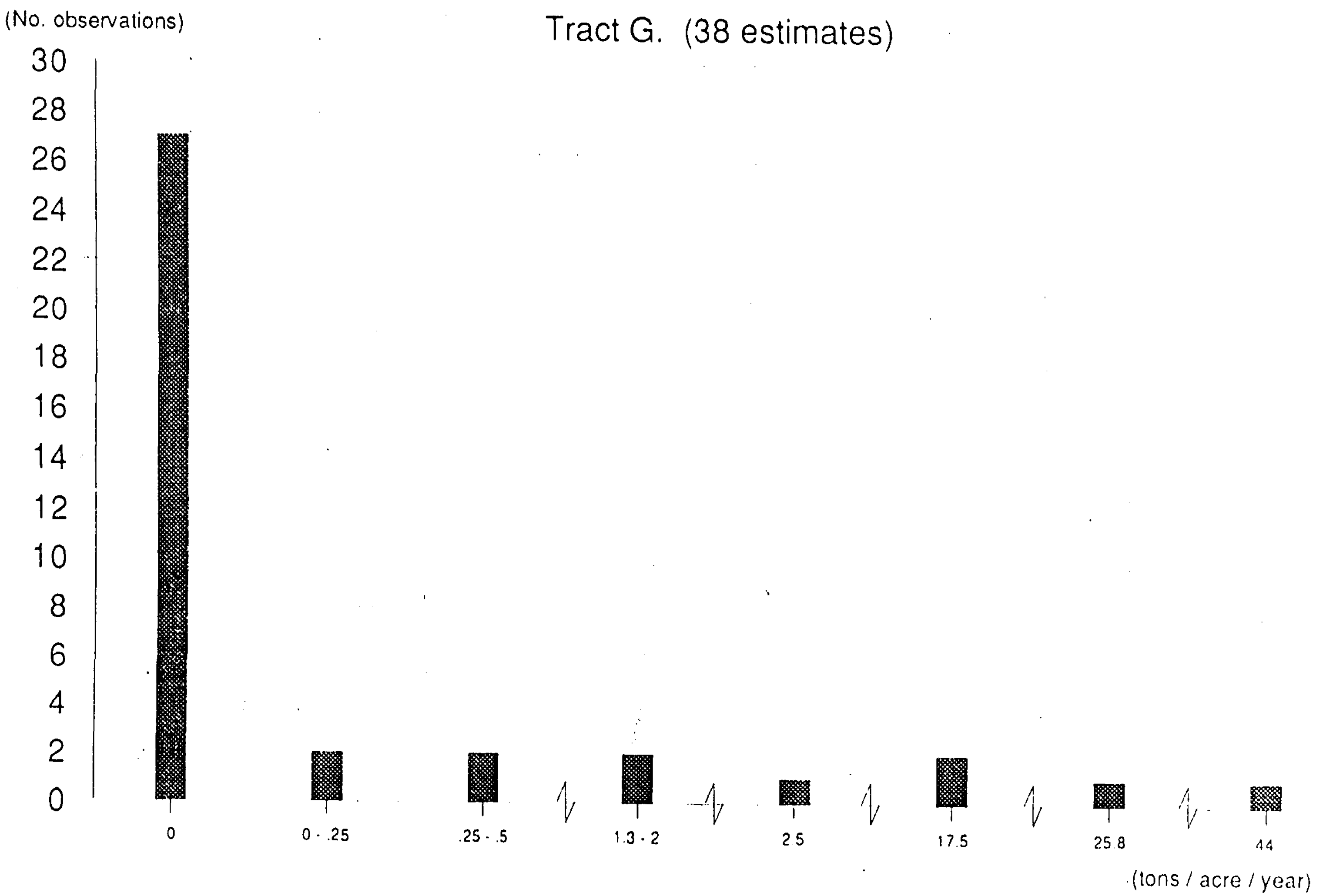


Figure 23. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

Harvesting took place between March and May, 1989. Data collection followed in late July, 1989. Only a portion of this tract was included in the plot data collection due to the uniformity of harvesting operations and time constraints. The entire tract was used to measure general (non-plot) tract information.

Sale boundaries consisted of a road to the north and east of the study area, and a streamside management zone to the south and west. Within these bounds, a combination of overland and bladed skid trails was used as shown in Figure 24. A fairly extensive network of trails was used in this harvest. Constructed skid trails accounted for 440 cubic yards of soil displacement, while the landing and truck turnaround area accounted for 10 and 77 cubic yards respectively. Another 37 cubic yards of soil was moved for unknown purposes bringing the total to 570 cubic-yards. Once again the tract layout was designed with its long axis along the contour.

Seventy-four percent of the surface area on Tract H was classified as undisturbed after harvesting and 11 percent was considered slightly disturbed. Fourteen percent was severely disturbed and one percent was covered by depression deposits. The sub-classifications of compaction, non-soil, and debris piles encompassed five, nine, and twelve percent of the tract surface area respectively.

Soils on the tract were classified as Edneytown-Peaks-Thurmond in Botetourt County's soil association guide published in the 1950's. These soils are derived from granite or granite-gneiss and described as a stoney, fine sandy loam.

The frequency distribution of estimated soil movement is shown in Figure 25. The highest estimate of 24.8 tons/acre/year was located on the landing. This spot was relatively gently sloping, but had no cover over the bare soil and no barriers existed to

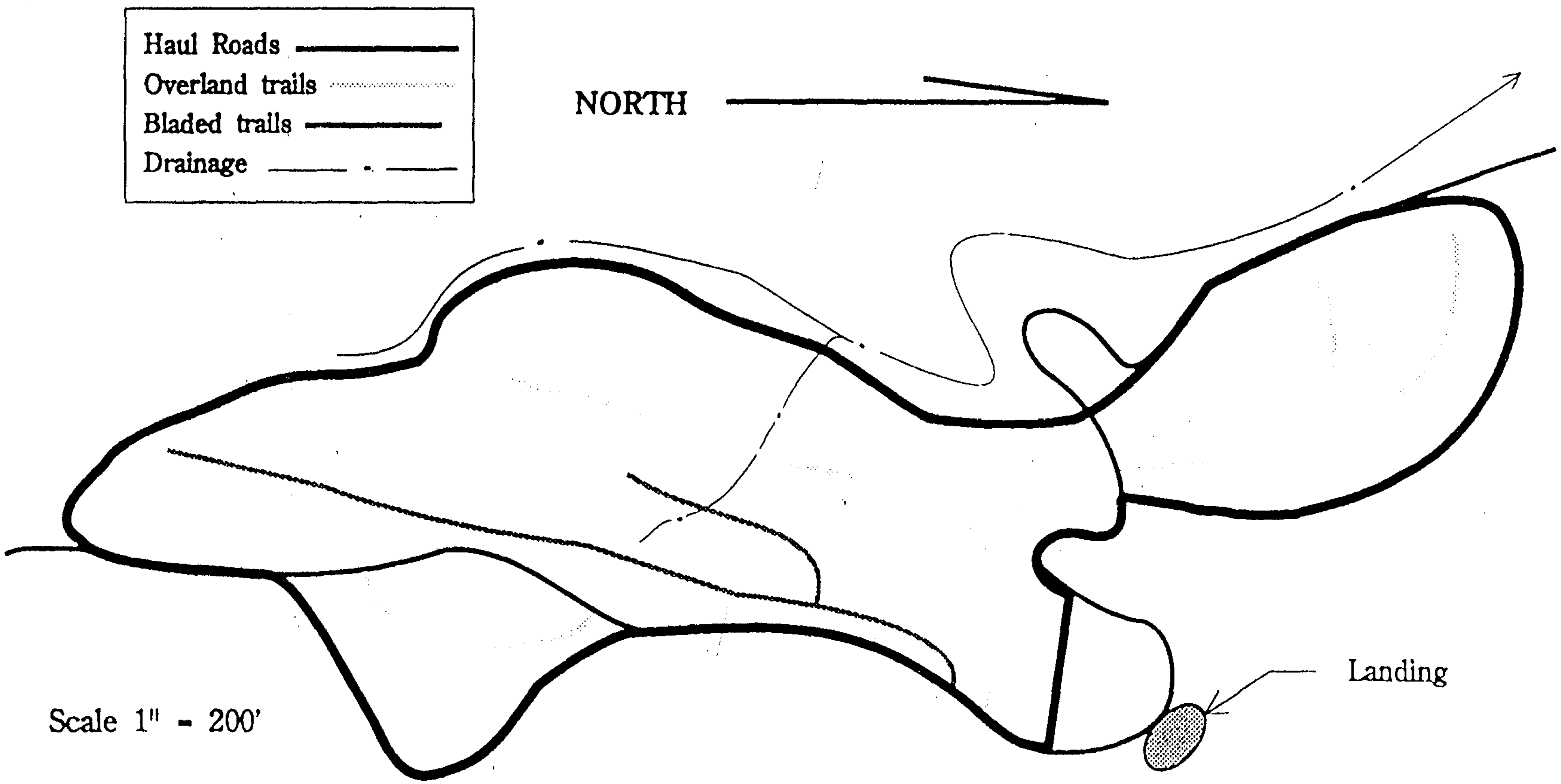


Figure 24. Map of tract H.

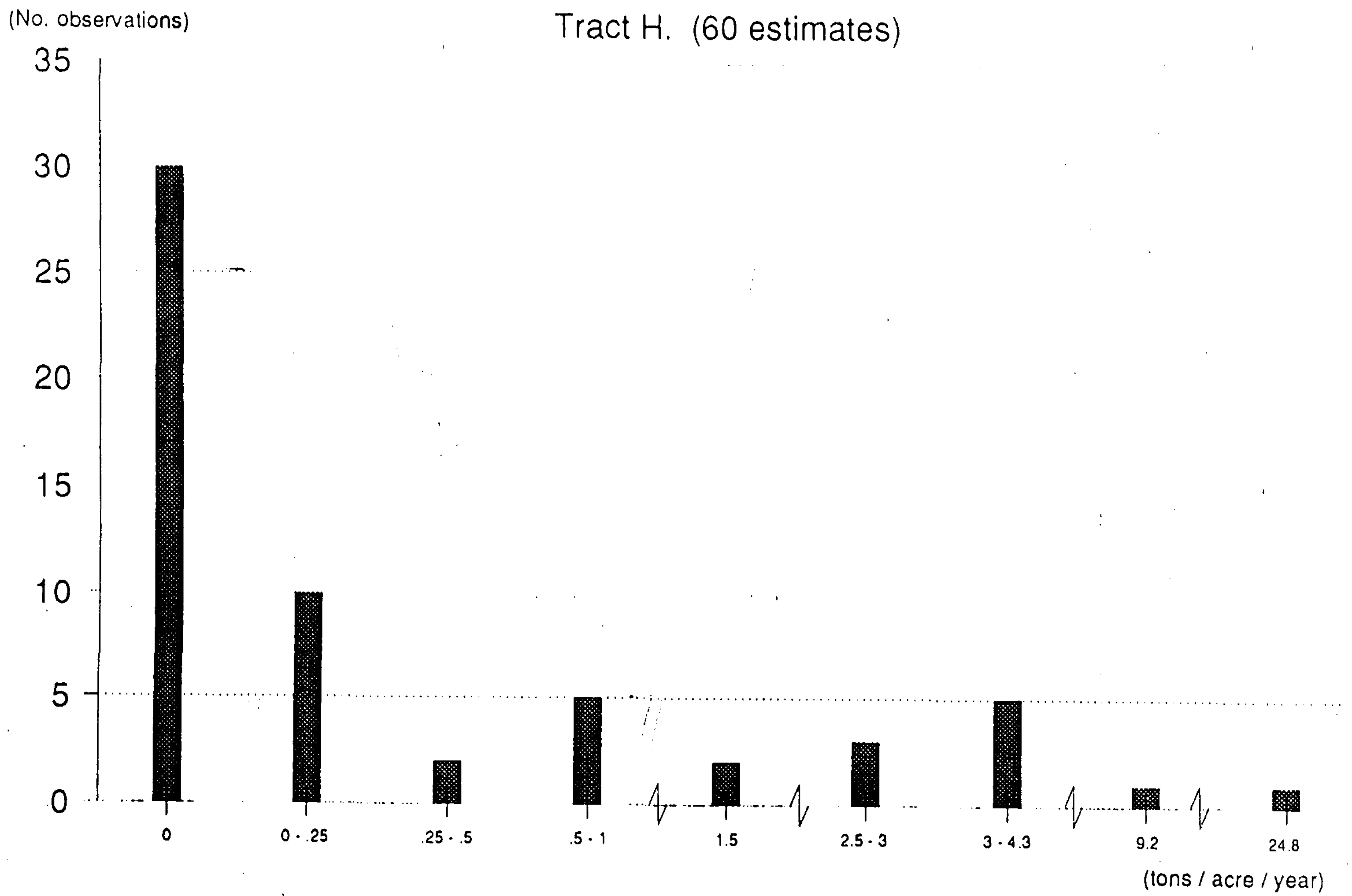


Figure 25. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

filter suspended sediment. The average of the 60 estimates on Tract H was 1.17 tons/acre/year. Further treatment of the two highest estimates would have dropped the average to 0.6 tons/acre/year and treating the five highest estimates would have decreased it further to 0.46 tons/acre/year. These figures again demonstrate the importance of proper job closure measures on critical areas (i.e., landings and skid trails next to haul roads and skid trails crossing or draining adjacent to water drainages).

Average mechanical strength measurements for undisturbed, slightly disturbed, and slightly disturbed/compacted areas are shown in Figure 26. Only one percent of the tract fell into the slightly disturbed/compacted class. Less than 10 observations are included in the penetrometer readings for this classification shown in Figure 26. The largest change in the slightly disturbed and slightly disturbed/compacted class took place between the first and third inch.

Tract I

Tract I (39.0 acres), located in Bedford County, is privately owned. This land is presently leased to a hunting club. The owner, in addition to receiving income from the sale of timber, was attempting to maintain sufficient wildlife values to support the lease. This tract was bounded by other private ownerships on three sides and a perennial stream to the north.

The harvesting was performed with a CAT 518 skidder equipped with 23.1x26 tires between May and August 1989. Data collection was done in late August 1989.

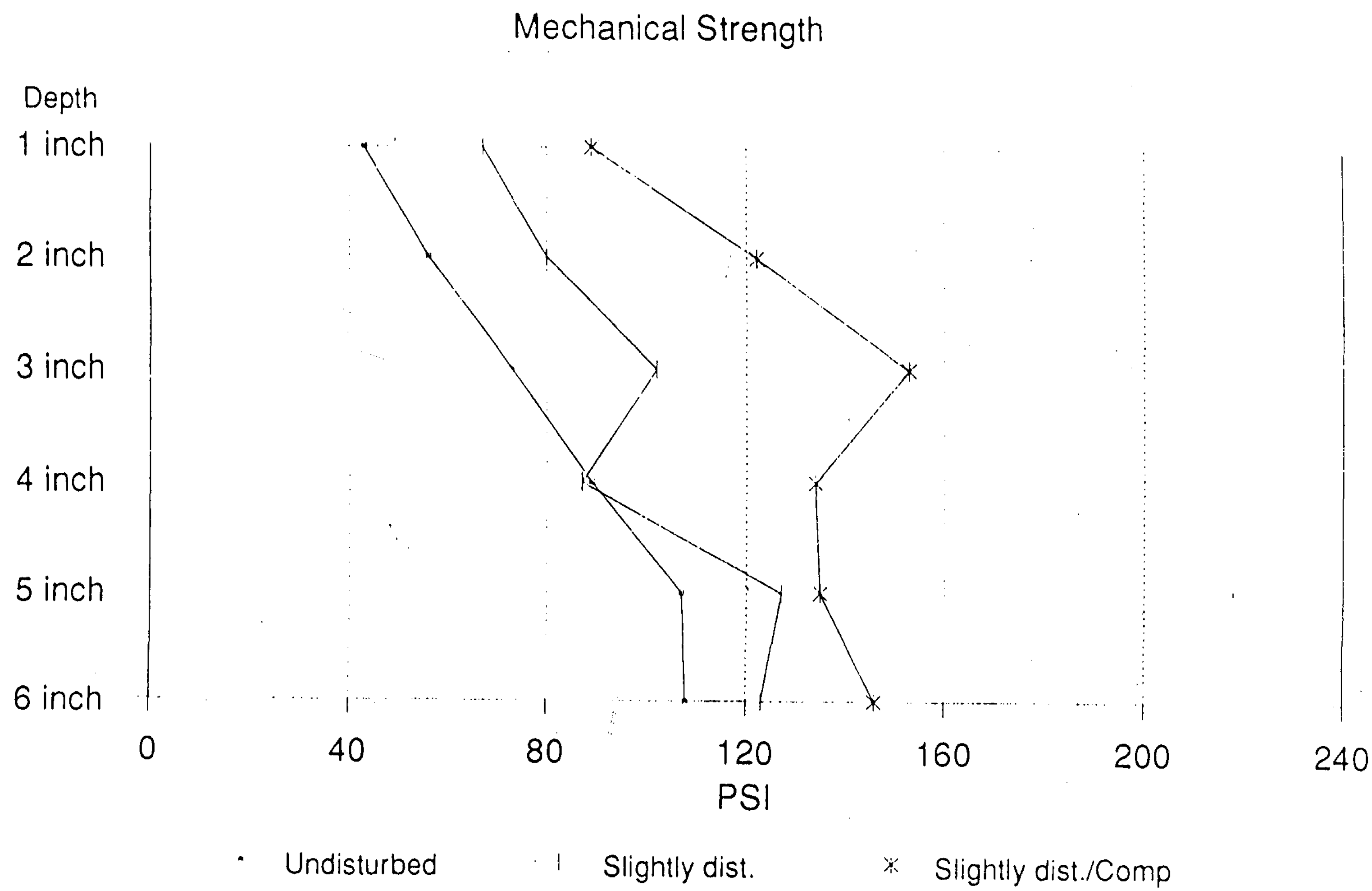


Figure 26. Average mechanical strength with depth on Tract H. (undisturbed, slightly disturbed, and slightly disturbed/ compacted).

Heavy, consistent rainfall during harvesting held up logging activities, increased the time soil was exposed, and delayed closure and seeding activities. Wet conditions made it difficult for the logger to maintain production without impacting the site. Maximum slopes of 65 percent on this unit added further limitations to access and forced the use of bladed skid trails with the exception of occasional overland spurs (Figure 27). The landing as well as all skid trails were located by the logger.

Soil displaced in the construction of skid trails totaled 1377 cubic yards. Additional soil movement took place on the landing (34 cubic yards), waterbars (80 cubic yards), and the haul road (31 cubic yards). Despite the relatively extensive network of bladed skid trails, 81 percent of the total tract area remained undisturbed after harvesting. Only six percent of the tract was classified as slightly disturbed. Thirteen percent of the tract was severely disturbed, and less than 0.5 percent of the area displayed depression deposits. The small amount of slightly disturbed area was a result of skidding being restricted to the bladed trails. The severely disturbed area was one of the largest in the study and was attributed to the construction of skid trails.

Sub-classes of compaction, non-soil, and debris piles covered four, two, and thirty five percent of the total tract surface respectively. Debris piles covered a larger percentage of the area than any of the other tracts in the study and gave added protection from soil erosion within the tract. Soils for Tract I were classified in the Edneytown series by the Bedford County soil survey. The texture of the soil is stoney, fine sandy loam. The site, for the most part, was well drained.

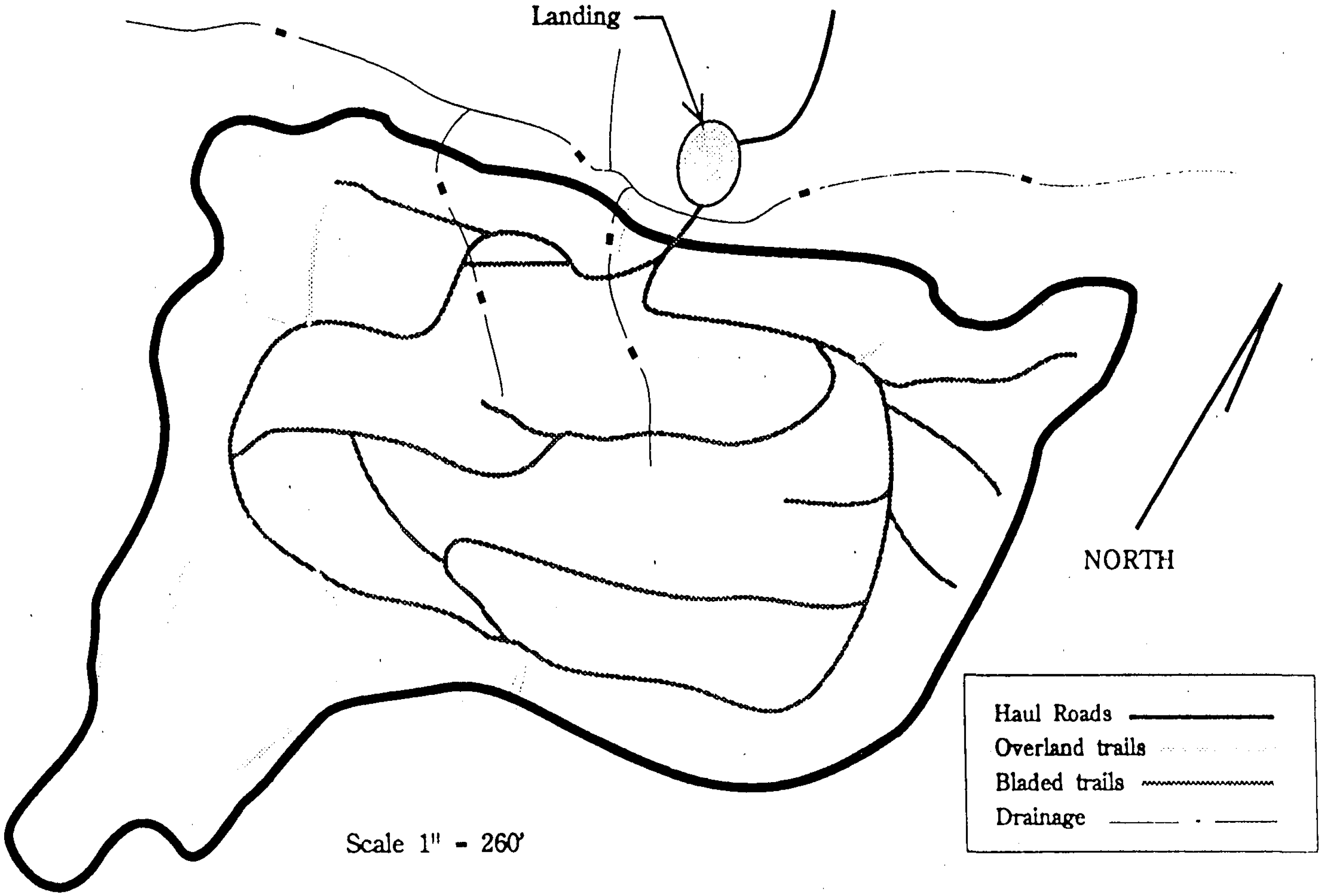


Figure 27. Map of tract I.

The histogram of the 82 potential soil movement estimates, from the Universal Soil Loss Equation (Figure 28), shows a wide distribution of erosion risk. The largest estimate of 22.1 tons/acre/year, was taken at the base of the tract next to a stream crossing. This point was left in an unclosed state at the request of the hunting club who wanted access into the area via the stream crossing. Had the area been laced with slash, erosion risk could have been reduced substantially. Additional high estimates on the tract were related to small drains at the toe of the slope emptying directly into the stream to the north. The average for all estimates was 1.01 tons/acre/year, and without the highest two estimates was 0.66 tons/acre/year.

Average soil mechanical strength values for the undisturbed, slightly disturbed, and slightly disturbed/compacted soils, are shown in Figure 29. The readings in the slightly disturbed/compacted category extended to the limit of the penetrometer's scale. This indicates that the production capabilities of the slightly disturbed/compacted conditions (approximately 1 percent of the tract surface), would be somewhat reduced.

Tract J

Tract J (19.9 acres), located in Highland County on the Jefferson National Forest, is managed by the U.S. Forest Service primarily for timber production. The tract was bounded by a permanent road to the north, a ridge to the west and a streamside management zone to the east. The layout was designed with the long axis along the contour which required the construction of bladed skid trails. A total of 997 cubic yards of earth were moved in skid trail construction. The construction of a haul road specifically for this tract resulted in the movement of 550 cubic yards of earth. Two small landings required eight cubic yards of earth to be moved, and about five cubic

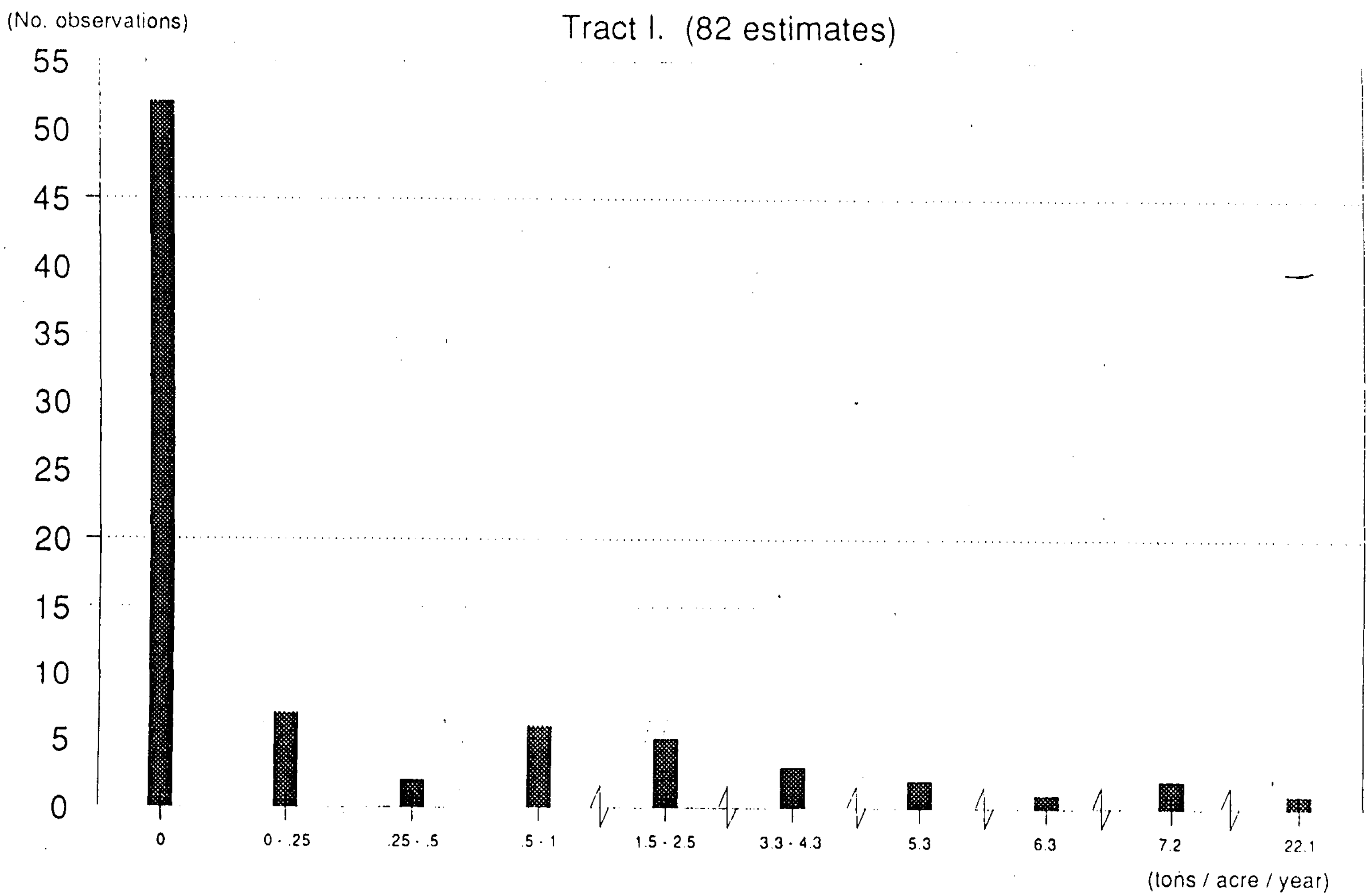


Figure 28. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

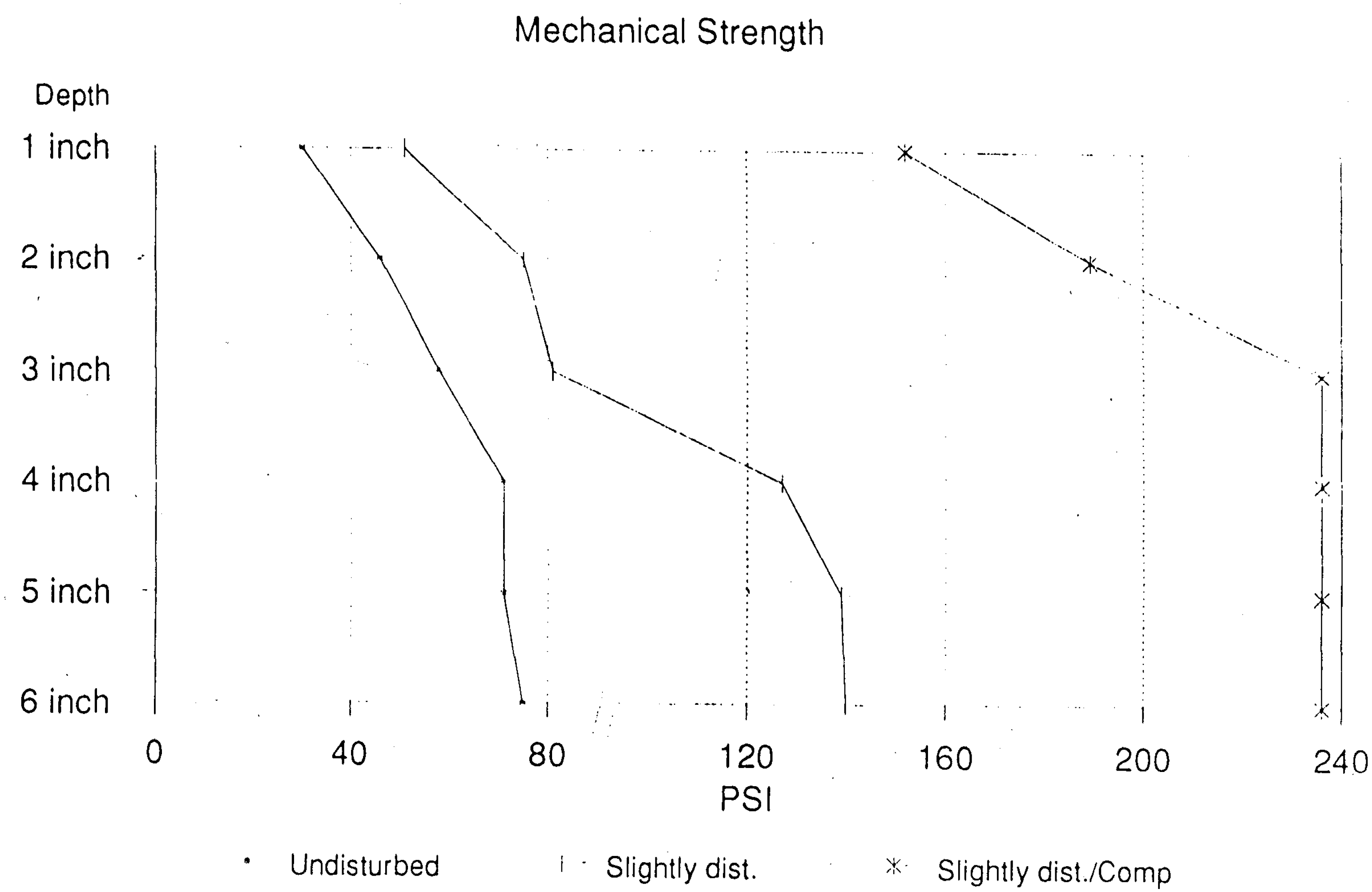


Figure 29. Average mechanical strength with depth on Tract I. (undisturbed, slightly disturbed, and slightly disturbed/ compacted).

yards were moved in waterbar construction. The locations of the landings, skid trails and haul road are shown in Figure 30.

The harvest took place between March and May, 1989 and the tract was visited for data collection in August, 1989. Close to a full growing season occurred before data collection giving vegetation a chance to regenerate. The tract was skidded with a John Deere 640 skidder mounted on 18.4x34 tires. Average slope for the tract was 31 percent, one of the steeper tracts in the study.

Plot data indicates that 75 percent of the total area was left undisturbed after the harvest; only two of the 75 percent was covered with dense debris piles. The slightly disturbed category included 15 percent of the tract surface and severely disturbed covered 10 percent of the area. Depression deposits were found on less than 0.5 percent of the tract area.

Sub-classifications included five percent of the tract surface in visibly compacted condition, one percent in the non-soil category, and nine percent covered by debris piles. Non-soil exhibited the lowest value of all tracts studied, which was a result of small amounts of rock outcrops and a low stocking level prior to harvest. Soils on the harvested site were classified by the National Forest Soil Association as Berks-Weikert-Rushtown series with a texture of shaly silt loam. The entire tract was well drained.

A histogram of the 38 potential soil movement estimates is provided in Figure 31. Only one of the estimates was above 5.5 tons/acre/year. This plot was located where soil had been pushed to construct a skid trail. The resulting 55 percent slope had no provision for storage or filtering runoff before it would reach a small stream east of

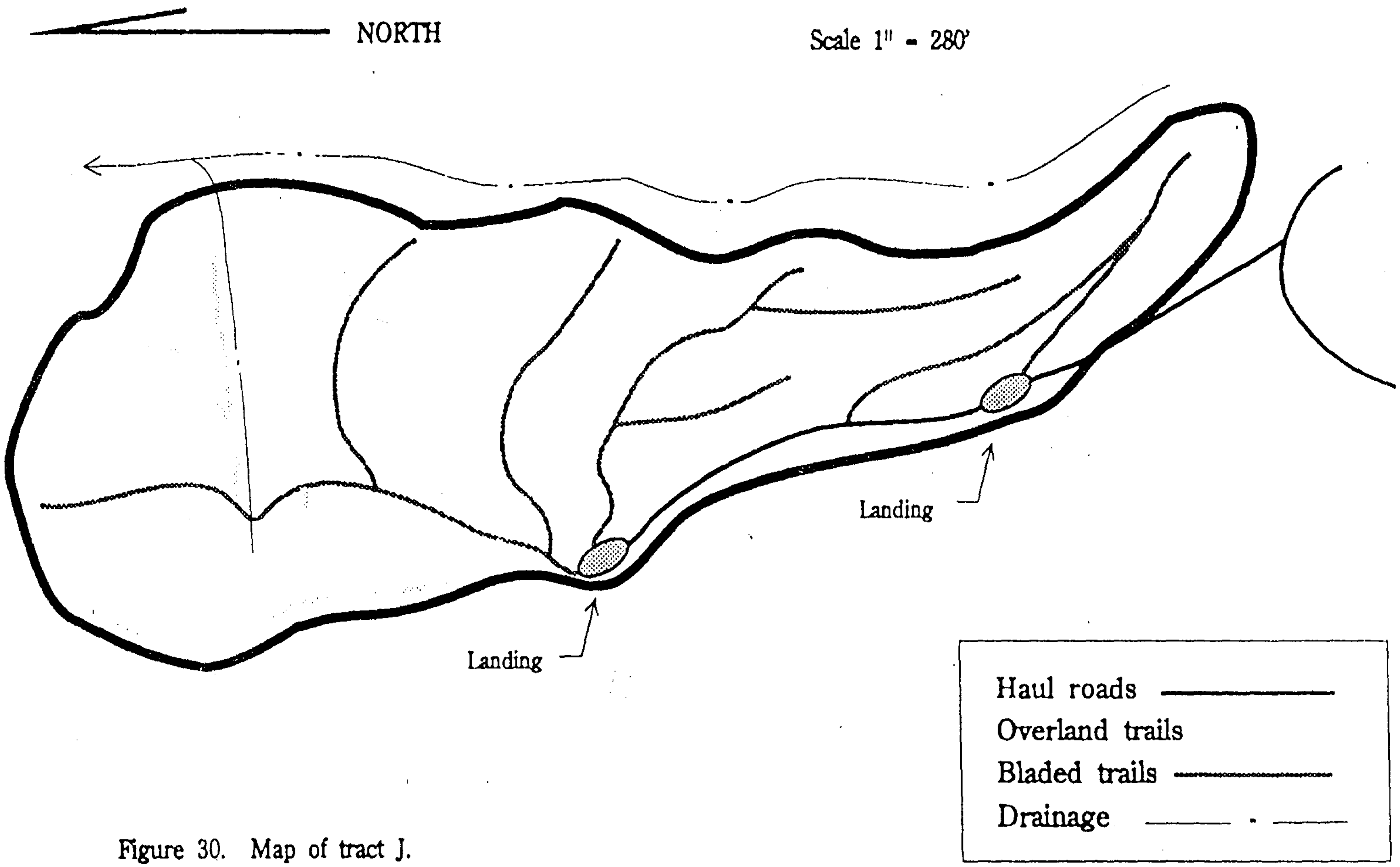


Figure 30. Map of tract J.

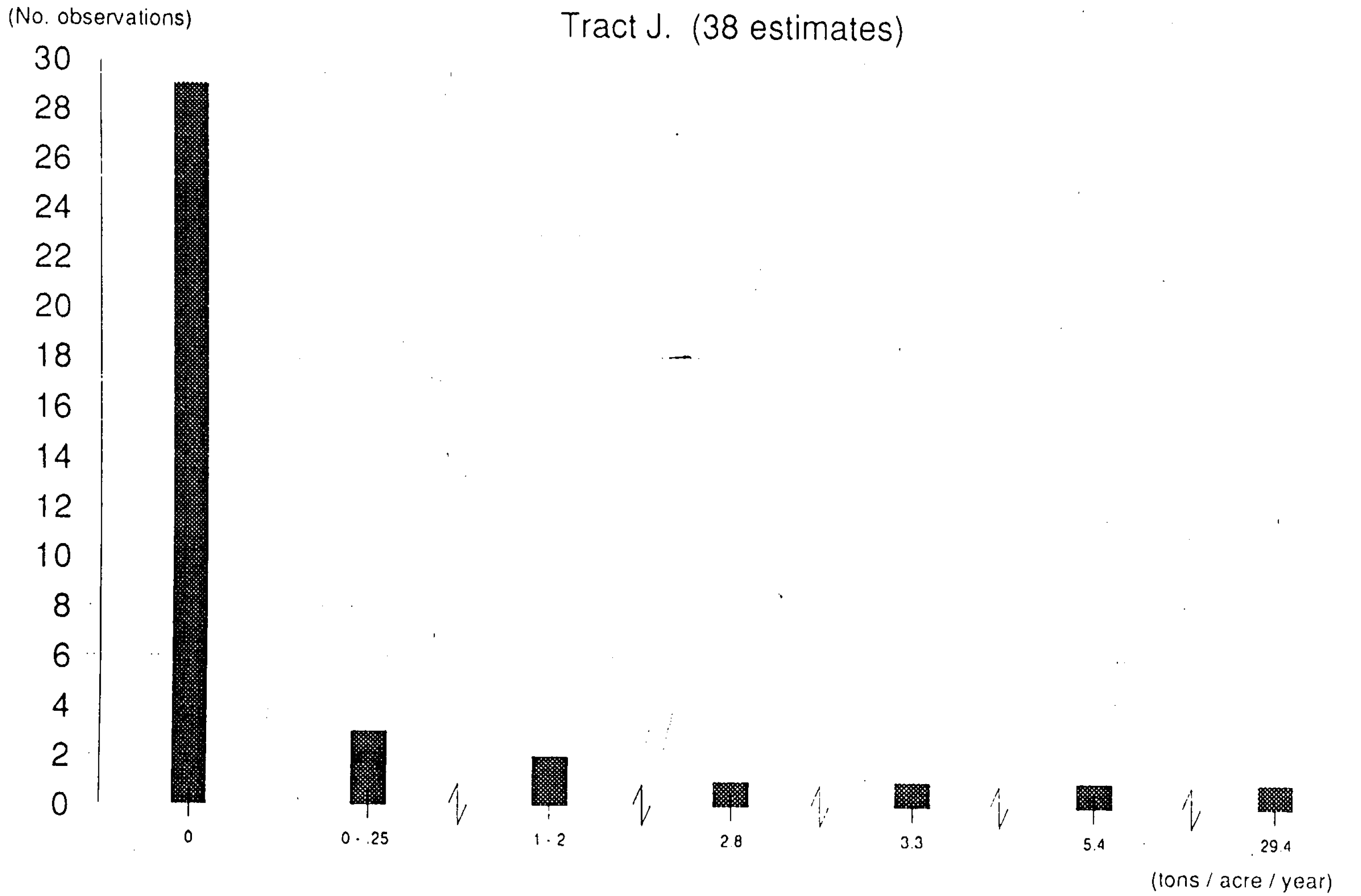


Figure 31. Frequency of potential soil movement estimates from the Universal Soil Loss Equation.

the harvest area. This posed the only serious erosion risk associated with the tract. If a little more care had been used when installing this skid trail, the erosion risk could have been reduced. The average potential soil movement estimate was 1.17 tons/acre/year. Without the two highest, it decreases to 0.26 tons/acre/year (a 4.5 fold decrease).

Average mechanical strength values for the undisturbed, slightly disturbed, and slightly disturbed/compacted areas on tract J are shown in Figure 32. Undisturbed and slightly disturbed readings were very similar for this tract, however, the slightly disturbed/compacted area, again consisting of less than 10 observations, was very similar to that of tract I (readings extended to the limit of the penetrometer's scale). Productivity of the area represented by this class (3 percent of the tract surface) may be decreased.

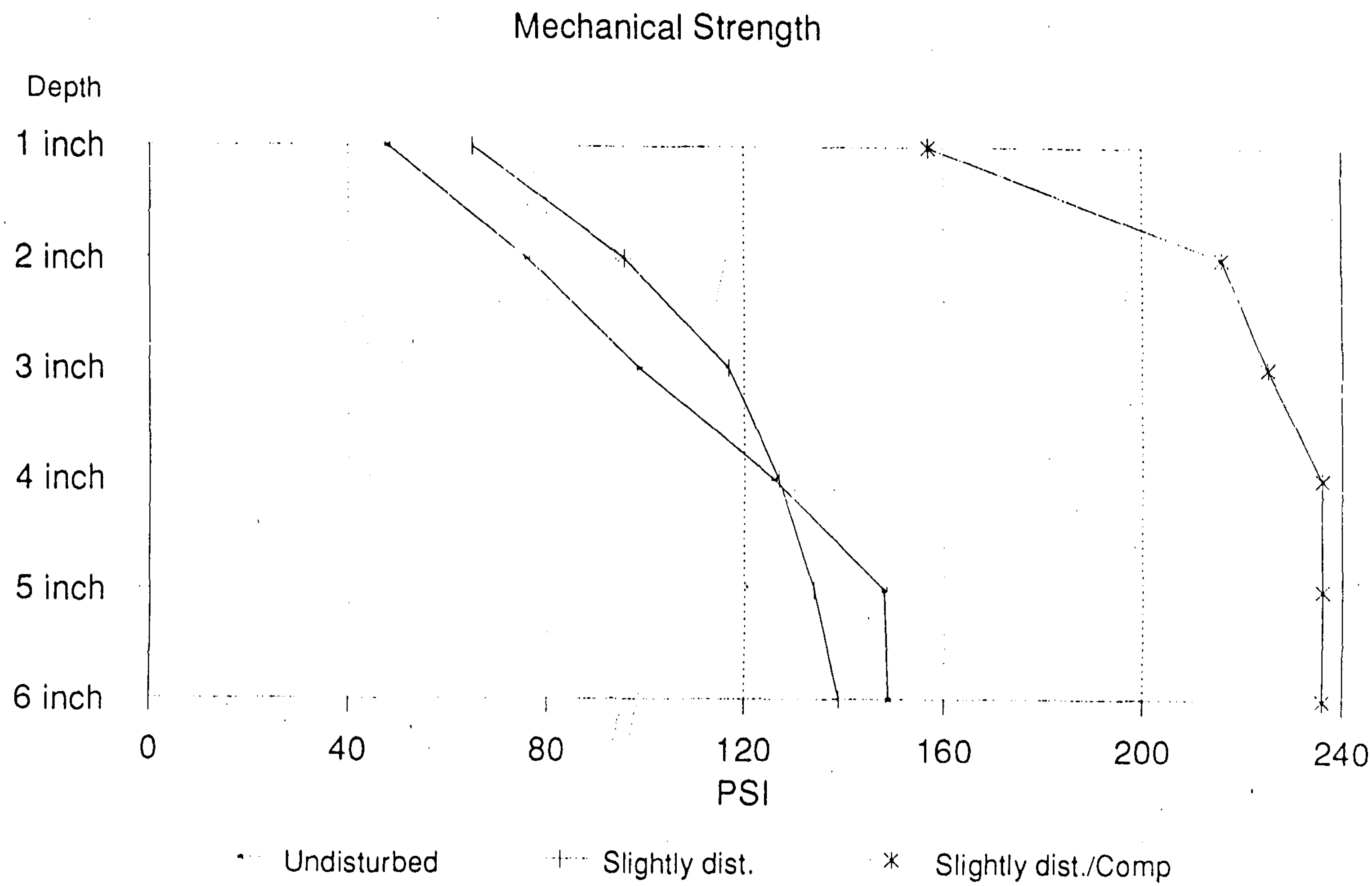


Figure 32. Average mechanical strength with depth on Tract J. (undisturbed, slightly disturbed, and slightly disturbed/ compacted).

(Discussion)

The two general harvest treatments, dispersed overland skidding perpendicular to the contours and concentrated skidding on bladed skid trails installed along the contours were compared to determine if either procedure had distinct advantages for maintaining site productivity or stream and water quality. These comparisons were limited by the relatively small number of tracts surveyed, but provide insight for planning future harvests.

Primary Soil Disturbance Classes

Undisturbed

In general, seventy to eighty percent of the surface area of the tracts remained undisturbed after harvest. A Wilcoxon Rank Sum Test found no difference (alpha = 0.2107) in the amount of undisturbed area between tracts with overland verses bladed skid trails (Table 3). On average, 77 percent of the tracts were undisturbed. In a comparable study by Miller and Sirois (1986), approximately 70 percent of the total tract area was undisturbed. Studies by Dickerson (1968) and Willis (1971) had similar estimates of undisturbed area resulting from harvests using rubber-tired skidders with 79 and 77 percent respectively.

Table 3. Comparison of undisturbed area (%) on tracts with overland skid trails and bladed skid trails using the Wilcoxon Rank Sum Test.

Tract	Percent undisturbed area using overland skid trails.	Tract	Percent undisturbed area using bladed skid trails	Rank
D	71			1
		G	74	2.5
		H	74	2.5
		F	75	4.5
		J	75	4.5
B	79			6.5
C	79			6.5
		I	81	9
A	81			9
E	81			9
Total Ranks:	32		23	

Slightly Disturbed

Areas characterized by slight disturbance ranged from 11 to 15 percent on nine of the tracts. Tract I had a low of six percent. The smaller area for Tract I appears to be a result of the steep slope and intense skid trail system; the need and ability to travel far from primary skid trails did not exist. The logger's experience (approximately 30 years) probably added to this low level of disturbance.

The hypothesis that the percentage of the tract falling into the slightly disturbed category differed between skidding methods was tested using the Wilcoxon Rank Sum procedure. No significant difference was found ($0.15 < \alpha < 0.210$) between bladed skid trails and overland skidding (Table 4).

These figures compare with those of Miller and Sirois (1986) who estimated roughly 13 percent of the sites they studied were left in this condition.

Severely Disturbed

The percentage of tract area in the severely disturbed class ranged from six to fourteen percent. Severe disturbance was more commonly associated with the construction of skid trails than with skidder damage. Landings, haul roads and waterbars were also major contributors of area within this class.

Table 4. Comparison of slightly disturbed area (%) on tracts with overland skid trails and bladed skid trails using the Wilcoxon Rank Sum Test.

Tract	Percent slightly dist. area using overland skid trails.	Tract	Percent slightly dist. area using bladed skid trails.	Rank
		I	6	1
E	11			3
		F	11	3
		H	11	3
A	12			5
B	14			6.5
		G	14	6.5
C	15			9
D	15			9
		J	15	9
Total Ranks:	32.5		22.5	

The hypothesis that the percentage of the tract in the severely disturbed class on the tracts where bladed skid trails were used was less than or equal to that on the overland skidded tracts was rejected (alpha < 0.008) using the Wilcoxon Rank Sum Test (Table 5). Overland skidding perpendicular to the slope, if done properly, results in significantly lower levels of severe disturbance.

Waterbar installation on bladed skid trails, where sub-soil had already been exposed, created very little additional disturbance. On the other hand, overland skid trails, which had original top layers of soil intact, experienced a noticeable increase in severe disturbance from waterbar construction. The overuse of waterbars as a means of potential erosion control on overland trails often resulted in a greater erosion risk than they were constructed to protect against.

Depression Deposits

Very few depression deposits of sediment were encountered during the field survey. Only three tracts (B, D, and H) reached a level of one percent of the total tract surface area. All tracts had small sporadic spots of sediment, generally along the edge of haul roads, behind sediment barriers established by the logger, or behind waterbars. The area in this category may increase slightly before the harvested area is completely revegetated, but major increases in sedimentation deposits are unlikely. These deposits can be considered evidence that tract layout and closure efforts were effective.

Table 5. Comparison of severely disturbed area (%) on tracts with overland skid trails and bladed skid trails using the Wilcoxon Rank Sum Test.

Tract	Percent severely dist. area using overland skid trails.	Tract	Percent severely dist. area using bladed skid trails.	Rank
B	6			1.5
C	6			1.5
A	7			3
E	8			4
D	10			5.5
		J	10	5.5
		G	12	7
		I	13	8
		F	14	9.5
		H	14	9.5
Total Ranks:	15.5		39.5	

Sub-Classifications of Soil Disturbance

Non-soil

The non-soil sub-class was composed of surface rock fragments, rock outcrops and stumps found on each study area. Stumps generally made up less than one percent of the surface area for each tract. Non-soil ranged from a low of one percent on Tract I to a high of nineteen percent on Tract B. Three of the overland skidded tracts (A, B, and C) had high percents of non-soil (13, 19, and 15 percent respectively). Only one of the contour skidded tracts, Tract F, had more than 10 percent tract surface in this sub-class. Large amounts of rock are not necessarily a criteria for overland skidding. Two tracts, (D and E) had relatively low percentages (3 percent each) of non-soil surface area and were effectively skidded overland.

The hypothesis that the percentage of non-soil area on overland skidded tracts was less than or equal to that on tracts with bladed trails was tested using the Wilcoxon Rank Sum Procedure (Table 6). No significant difference was found (alpha = 0.111).

Debris Piles

Debris piles are a function of the volume and quality of the timber on a tract prior to harvest. This sub-class ranged from six percent on tract B to 35 percent on Tract I. All systems in the study relied on full or partial delimbing at the stump. Most of the slash was left at the stump and a single large accumulation of slash near the landing. No significant difference (alpha = 0.50) was found between tracts with overland versus bladed skid trails using the rank sum test (Table 7).

Table 6. Comparison of non-soil area (%) on tracts with overland skid trails and bladed skid trails using the Wilcoxon Rank Sum Test.

Tract	Percent non-soil area using overland skid trails.	Tract	Percent non-soil area using bladed skid trails.	Rank
		J	1	1
		I	2	2
D	3			4
E	3			4
		G	3	4
		H	9	6
A	13			7
		F	14	8
C	15			9
B	19			10
Total Ranks:	34		21	

Table 7. Comparison of area (%) covered by debris piles on tracts with overland skid trails and bladed skid trails using the Wilcoxon Rank Sum Test.

Tract	Area with debris piles on tracts with overland skid trails.	Tract	Area with debris piles on tracts with bladed skid trails.	Rank
C	6			1
		J	9	2
		F	11	3
		H	12	4
A	15			5.5
D	15			5.5
B	23			7
E	24			8
		G	31	9
		I	35	10
Total Ranks:	27		28	

Debris piles, considered to impede regeneration activities on the coastal plain and piedmont sites, are an important form of soil protection in mountainous terrain. Beneficial aspects of slash include reducing raindrop impact, slowing overland water flow, and adding protection to the ground surface from skidder traffic.

Compaction

Compaction influences the success of regeneration following timber harvest. Field data collection relied on ocular estimates of compaction on each plot. Severe compaction was easily defined in the field. Differences between the slightly disturbed and slightly disturbed/compacted classifications were more judgmental. Table 8 was constructed to test the validity of these observations. The paired t-test procedure was used to test for significant changes in soil mechanical strength. Significant differences were found in the surface layers of two of the slightly disturbed tracts (D and I), but the absolute change was relatively small. The small changes shown for uncompacted and the relatively large changes for the compacted sub-category indicates that the ocular estimates were sound.

The slightly disturbed/compacted classification ranged from less than one to five percent of the tract areas. The resulting small sample size limited the ability to test the significance of the measured change in soil mechanical strength. The changes found were large, but considering the small areas involved, this disturbance would have a relatively small impact on site productivity.

The severely disturbed class was broken into two groups of mechanical strength observations. These were a) unconsolidated, loose soil (pushed soil) as found in most

Table 8. Average mechanical strength differences (psi) between paired data samples of the undisturbed class and listed class.

Slightly disturbed class

(Tract)	A	B	C	D	E	F	H	I	J
% of tract occupied by this class	12	14	15	15	11	11	11	6	15
(Depth inches)									
1	**-4**	**0**	**5**	***13**	**-2**	**0**	***30**	*20*	**6**
2	**11**	**1**	**1**	***29**	**-2**	**-3**	***33**	*34*	**7**
3	**14**	**4**	**-7**	***39**	**4**	**2**	***50**	*39*	**9**
4	***24**	**11**	**-26**	***40**	**12**	**-11**	3	*67*	-5
5	***40**	**5**	**-28**	***27**	**6**	**-11**	25	*76*	-25
6	***59**	**2**	**-31**	***26**	**-8**	**-7**	28	*71*	-24

Slightly disturbed/compacted class

(Tract)	A	B	C	D	E	F	H	I	J
% of tract occupied by this class	2	2	2	5	2	1	1	1	3
(Depth inches)									
1	*35*	*13*	*104*	***63**	**15**	*25*	*33*	*139*	*106*
2	*90*	*26*	*132*	***70**	**28**	*48*	*54*	*146*	*131*
3	*138*	*47*	*145*	***84**	**18**	*110*	*56*	*191*	*119*
4	*137*	*57*	*98*	***79**	**42**	*52*	*15*	*173*	*99*
5	*135*	*63*	*89*	**37**	**23**	*68*	*3*	*169*	*71*
6	*140*	*70*	*68*	***57**	**16**	*63*	*14*	*169*	*91*

* - represents values significantly different at the 95% confidence level.
(00) - had less than ten observations within the sample.

waterbars and reposed soil from bladed roads and b) in place, exposed subsoil which had been cut or rutted. These two forms of severe disturbance had different mechanical strengths. In general, the mechanical strength of pushed soil was low, while the cut soil, usually sub-soil, was high.

All severely disturbed/compacted and severely disturbed (cut/rut) areas on the tracts had mechanical strengths beyond the penetrometer's scale. All areas in this category had soil mechanical strengths that would reduce root growth potential by 30 percent or more.

Soil Moved in Earthwork

The amount of soil movement associated with overland skidding was minimal. Most of this was a result of haul road construction rather than timber extraction operations. The hypothesis that the amount of soil disturbed on tracts where bladed trails were used was equal to or less than that on tracts harvested with overland skidding was tested using the Wilcoxon Rank Sum Test (Table 9). The hypothesis was rejected (alpha = 0.004). Contour skidding, using bladed skid trails parallel to contour, resulted in significant increases in the amount of soil movement. Only one of the tracts (Tract F) using bladed skid trails had less than 500 cubic yards of soil displaced. Three of these tracts (H, I, and J) resulted in movement between 500 and 1500 cubic yards, and tract G required over 2100 cubic yards of earth to be excavated.

Table 9. Comparison of skid pattern and soil volume movement (cubic yards/acre) per tract for skid trail construction using the Wilcoxon Rank Sum Test.

Tract	Skid Pattern	Soil Volumes Moved for Skid Trails	Rank
A	perpendicular to contour	0.5	3.5
B	perpendicular to contour	0.5	3.5
C	perpendicular to contour	0.8	5
D	perpendicular to contour	0.3	2
E	perpendicular to contour	0	1
		Total	15
F	along contour	38	8
G	along contour	106	10
H	along contour	19	6
I	along contour	35	7
J	along contour	50	9
		Total	40

Soils disturbed by timber harvests often decrease site productivity and increase the potential for sedimentation and erosion (Patric 1980). Large volumes of soil movement associated with contour skidding are a common source of erosion and sedimentation. Erosion and sedimentation problems can be alleviated to a large extent through proper post harvest treatment of sites (Berglund 1978). However, if the increased risk of erosion and sedimentation from these earthworks can be avoided by overland skidding, the aesthetic values of the land and water quality would be maintained. A poor medium for plant growth results from stripping surface soil from the site. Overland trails, on the other hand, leave surface soil in place and appear to revegetate quickly.

Tract Closure

Waterbar construction accounted for most of the soil movement during tract closure. The installation of waterbars, in many instances, increased the potential soil loss estimates. Waterbars were often incorrectly installed, forming temporary dams. Surface runoff had cut through or diverged to one side of several older waterbars, continuing down the center of a skid trail, causing increased erosion. More waterbars than necessary were installed on several of the tracts to demonstrate to the landowner or the timber sale administrator that a serious effort at erosion control had been made. This over construction resulted in a net increase in erosion risk.

The soil movement estimates demonstrated that additional treatment on a few high risk locations could have greatly reduced the overall potential soil loss from a tract

after harvest. Table 10 shows a comparison of the tracts on a basis of the arithmetic mean generated from the field measurements and levels which would have resulted from treating the two and five points with the highest estimates of potential soil movement. The medians of these estimates are given as well.

By treating only two points more thoroughly, seven of the ten tract estimates would have dropped below 0.58 tons/acre/year. Potential soil loss on the other tracts (A, B, and G) would have been reduced considerably. Better closure of five areas with the highest estimates would reduce all tract averages, except A, B, and G, below 0.6 tons/acre/year. Tracts A, B, and G are reduced to below two tons/acre/year. Estimated averages from the Universal Soil Loss Equation do not take into consideration the healing of a site over time. Therefore these estimates, taken shortly after harvest, represent maximum potential erosion. These values will diminish over time as a result of increasing vegetative cover and root stabilization of the surface soil (McKee et al., 1985).

A large portion of the sedimentation and erosion risk found on the ten study areas was limited to "on-site" movement. In most instances, the "on-site" soil relocation was incapable of reaching streams or moving off site. Therefore, this soil movement posed little to no risk of stream sedimentation.

Table 10. Potential soil movement estimates by tract in terms of median, arithmetic average, and treated averages using field plot data.

Tract	Median	Arithmetic Average	* Added Closure Average	**Intensive Closure Average
A	0	3.37	2.10	1.49
B	0.04	2.86	2.21	1.90
C	0	0.41	0.27	0.14
D	0	0.37	0.27	0.12
E	0	0.21	0.12	0.05
F	0	1.08	0.83	0.58
G	0	2.94	2.01	1.06
H	0.01	1.17	0.60	0.42
I	0	1.01	0.66	0.45
J	0	1.17	0.26	0.04

* - Arithmetic average assuming the two highest soil movement estimates equal zero.

** - Arithmetic average assuming the five highest soil movement estimates equal zero.

Potential soil loss (off-site sedimentation) was estimated using the Universal Soil Loss Equation using average values from plot data for estimating soil movement and a total tract parameter to estimate on site storage. The result is an estimate of the volume of soil which would be lost from the tract in the period immediately following harvest. These estimates ranged from .099 to 1.048 tons/acre/year as shown in Figure 33.

Percent Area in Skid Trails

The area of each tract exhibiting noticeable skid trails is shown in Table 11. The area occupied by skid trails in this study is lower than 20 to 50 percent found in studies conducted in the Piedmont and Coastal regions. This difference is attributed to the inability to skid at random on the steep and rough terrain, the high cost of skid trail construction, and careful planning of skid trail locations.

The hypothesis that the percentage of tract area in skid trails on contour skidded tracts was less than or equal to that on overland skidded tracts was tested using the Wilcoxon Rank Sum Test. The hypothesis was rejected at the 0.075 level, indicating that overland trails consume less area.

No obvious relationships were found in this study between site disturbance and equipment, skid direction, volume of harvested product, and/or aspect. Some correlation may exist between these factors and the amount or severity of ground disturbance, but more detailed procedures are needed to reveal these relationships.

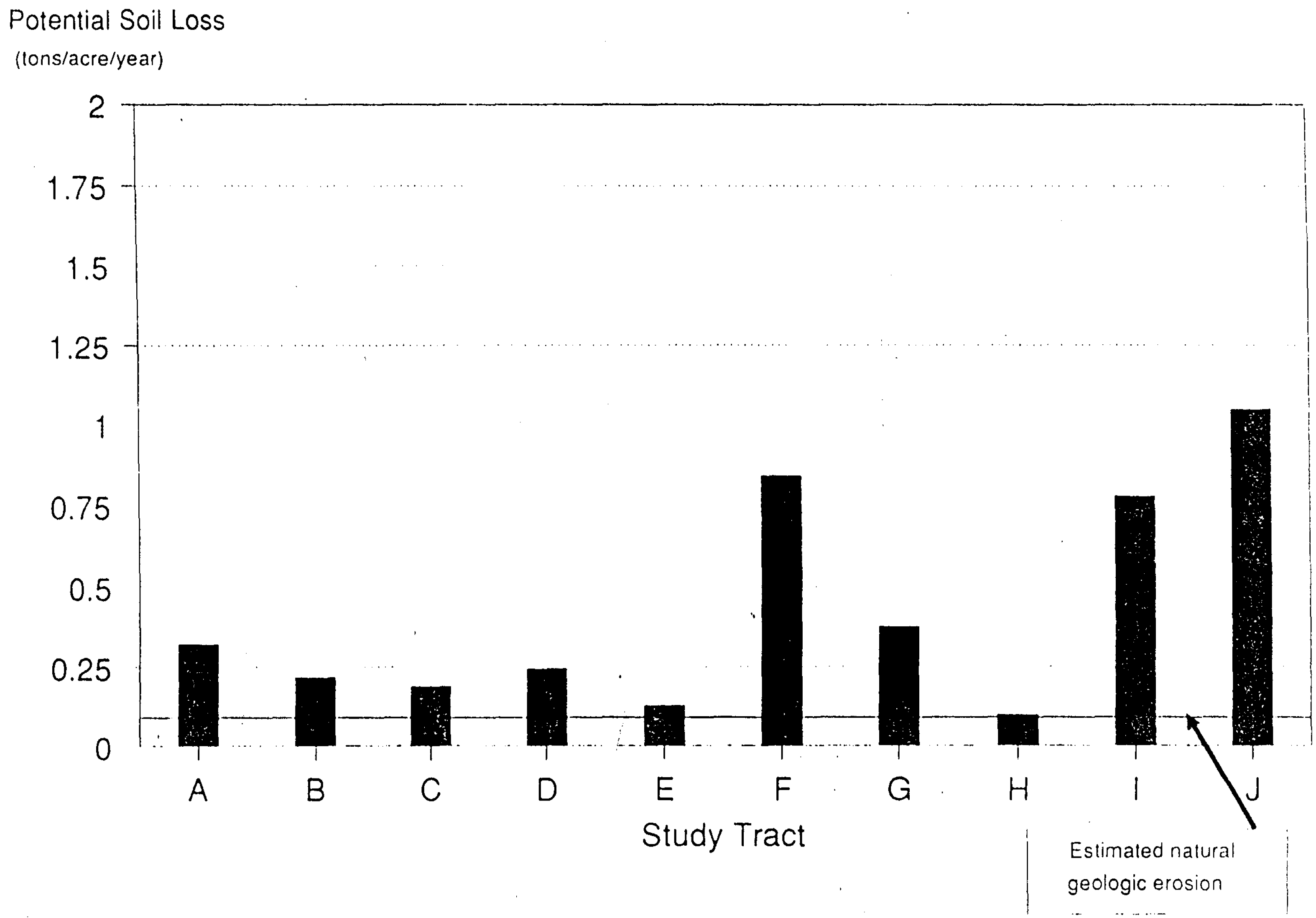


Figure 33. Potential soil loss estimates using the Universal Soil Loss Equation modified for forested land.

Table 11. Percentage of area covered by skid trails on tracts with overland and bladed skid trails using the Wilcoxon Rank Sum Test.

Tract	Tract Percent in Overland Trails		Rank
A	4		2.5
B	3		1
C	9		8.5
D	6		5.5
E	4		2.5
		Total	20

Tract	Tract Percent in Bladed Trails		Rank
F	6		5.5
G	9		8.5
H	7		7
I	5		4
J	10		10
		Total	35

Summary and Conclusions

The objective of this project was to assess the effect of current timber harvesting practices on slopes greater than 30 percent in the mountainous terrain of Virginia. Ten clear-cut areas were observed in their post harvest state. Documented site characteristics included: soil series, ownership, tract size, average slope, aspect, season of harvest, rainfall during harvest, skid trail type, equipment used (make, model, and tire size), skid direction relative to slope, product volume removed, and road and landing locations. In addition, a line plot sampling procedure was used on each tract using 20-foot diameter plots to take detailed measurements of disturbance types and causes. The detailed measurements covered from five to eight percent of the individual tract surface area. Data collected on each plot included a map of disturbance classes. Four disturbance classes were used - undisturbed, slightly disturbed, severely disturbed, and depression deposits. Areas within these classification were further defined using sub-classifications of compaction (showing visible evidence of surface depression by machine or log traffic), non-soil (including surface rock and stumps), and debris piles left by limbing activities. Cone penetrometer readings were taken within each disturbance class for each plot and paired with the closest undisturbed reading either within the plot or immediately adjacent to the plot.

All of the tracts were harvested between June, 1988 and August, 1989. The logging crews, while harvesting the tracts, had no knowledge that the tracts would be included in this study. Two major harvesting strategies were observed. If the long axis of the sale area was perpendicular to the contour, the harvesting crews favored overland skidding up and down the slope. This technique required minimum soil disturbance from skid trail construction but did subject more of the area to machine travel. If the long axis of the tract was parallel to the contour, the operations favored a contour skidding approach which involved constructing a network of bladed skid trails to gain access to all parts of the tract. This approach generally involved more earthworks in the form of skid trail construction, but minimized the amount of machine movement over the adjacent forest floor. Five tracts harvested by each technique were included in the study. Two of the tracts, one overland skidded and one contour skidded, were harvested by the same contractor.

Site Disturbance

The total tract area disturbed by harvesting averaged 20 to 30 percent of the tract area for both of the operating methods. The percentage of the tract area falling into the severely disturbed area was generally greater for tracts using contour skidding (13 percent) than for tracts using overland methods (7 percent).

An additional 11 to 15 percent of the tract area was classified as slightly disturbed. Only one tract had less than ten percent of tract area in this class. A low of six percent was found on Tract I, which had an extensive network of bladed skid trails and slopes in excess of 60 percent.

These data indicate that where ownership, tract boundary, and terrain conditions permit, an up and downhill skidding approach should be favored to diminish the visual impact of the harvest and overall erosion and sedimentation risk. Depression deposits were found on less than one percent of the tract area regardless of the skidding method. These deposits were found primarily behind waterbars and other sediment control barriers, and along the edges of roads. This low percentage indicates relatively small amount of long distance transport of soil by runoff following the harvests.

Site Disturbance Sub-classifications

Sub-classifications of non-soil, compaction, and debris piles were used to further describe the primary disturbance classes above. Rock outcrops and stumps, included in the undisturbed class, ranged from one to nineteen percent of tract surfaces. Stumps covered less than one percent while rock outcrops and fragments accounted for the majority of this sub-class.

Compaction was fairly difficult to document in the field. Consequently, two definitions were maintained throughout the project. The first was defined as a measurable change in soil mechanical strength. This change may or may not affect site productivity during the next rotation. A second definition was applied to those sites where the mechanical strength of the soil was 236 psi. A review of the literature indicates that this represents a point where the root growth potential of seedlings and herbaceous plants is reduced by approximately one third.

Some change in soil mechanical strength was found in the slightly disturbed/compacted areas, but only on Tracts I and J did this exceed the 236 psi level.

This covered two and three percent of the tract surfaces respectively. All tracts had compaction above 236 psi in the severely disturbed (cut/rut) and severely disturbed (compacted) categories. The extent of these ranged from one to five percent of the tract surfaces depending on the amount of soil moved in skid trail and landing construction. The severely disturbed (compacted) areas resulting from timber harvesting were less than three percent of the total tract areas in all cases.

The percentage of tract areas covered by debris piles ranged between six and thirty five percent depending on the quality and density of timber stand removed and the limbing practices used during harvesting. Additional research is needed to assess the effect of debris piles on stream sedimentation. Slash does protect the soil by reducing raindrop impact and by providing some filtration of surface runoff.

Soil Moved in Earthwork

The volume of soil moved in earthworks was a function of the skidding method used and the amount of haul roads contained within the tract boundaries. Skid trail construction on tracts with bladed skid trails resulted in the movement of between 440 and 2128 cubic yards of earth. The overland skidded tracts resulted in minimal soil movement associated with skidding (from 0 to 12 cubic yards).

Waterbars and landings required modest amounts of earth movement. Waterbar construction on overland skidded tracts did increase the exposure of mineral soil considerably. This impact was less on tracts with bladed trails (the soil was already exposed). Haul roads constructed specifically for the harvest resulted in considerable

amounts of earth movement on four of the tracts evaluated. Volumes moved for haul roads ranged from 31 to 880 cubic yards.

Percent Skid Trails

The total surface area in skid trails was more a function of tract geometry (shape and topography) than of the skidding method. Constructing bladed trails did not reduce the percentage of area covered, but did increase the severity of the soil disturbance. The analyses indicate that the damage (increased risk of sedimentation and increased compaction) caused by overland skidding perpendicular to the contour on these steep sites is less harmful from the standpoint of sedimentation, reduced growth potential, and aesthetics than that caused by installation of bladed trails to permit contour skidding.

Tract Closure

In many cases, the excess number and improper construction of waterbars during tract closure was a potential source of increased erosion risk. Waterbar construction requires blading of surface soil into a barrier to divert surface runoff. The increased mineral soil exposure and difficulty of reseeding exposed sites can result in a net increase in soil erosion. Tract F had one of the highest estimates of soil movement because of the spotty grass catch on mineral soil exposed during tract closure activities.

Average soil erosion estimates using the Universal Soil Loss Equation range between 0.21 and 3.37 tons/acre/year showing that the contractors had made a conscious effort to diminish the risk of erosion on the tracts. Dramatic decreases in the

estimated soil loss could have been achieved on many of the sites if measures had been taken to further treat a few "hot spots" that had extreme erosion risks. Many of the areas appeared to be adequately treated until a total review of the factors contributing to the erosion risk was made. Further education of contractors and logging crews in identifying and treating these "hot spots" is required if the overall goal of erosion reduction is to be achieved.

Recommendations

The field work, data analysis, and summary of the information collected for this study suggest several strategies which can be of assistance in the effort to reduce the impacts of harvesting on steep terrain. These suggestions have been grouped into three broad sections - harvest scheduling, tract layout, and harvest closure.

Harvest Scheduling

Tracts on poorly drained sites, finely textured soils with low rock content are more susceptible to damage if logged during wet weather. These tracts should be cut during the drier seasons of the year, especially during the summer months when evaporation and transpiration help reduce soil moisture content. Harvesting contractors should be provided with some flexibility in scheduling or contract extensions to reduce the urgency of cutting these tracts when the potential for damage is high. Creating ruts, blading skid trails, and causing other forms of disturbance are expensive for the contractor in terms of the energy wasted, stress to the machines in creating the damage, and work needed to achieve proper tract closure. Improved scheduling will be easier as

a better understanding is gained of operating system capabilities and better quality soil survey data becomes available for forested land in the mountain regions.

Tract Layout

This research indicates that skidding perpendicular to the contour results in less overall soil disturbance and erosion risk to the site. Where it is feasible and can be properly carried out, harvesting areas on moderately steep slopes (those ranging from 30 to 45 percent slope) should have the long axis of the tract running perpendicular to the contour. On slopes greater than 45 percent, safety and common sense dictate the use of contour skidding patterns. In these instances, tract layout with the long axis along the contour is the better alternative. If bladed trails must be used, they should be constructed as far away from streams as possible.

No attempt was made during this study to evaluate the placement of the landing and haul roads within the tract boundary. However, these two features of harvest layout are major contributors to soil movement and additional efforts in evaluating the economic and soil impacts is necessary.

Harvest Closure

Waterbars are an important means of reducing erosion and sedimentation risk from timber harvest on steep slopes. However, the number and placement of waterbars requires careful consideration to assure that they do not become a serious source of sedimentation. On several of the sites, the contractor had installed waterbars based upon a formula that dictated their spacing on the basis of slope alone. Consequently, this disturbed areas that were adequately protected by vegetation and rock fragments. Overland skidding across rocky areas results in minimal risk of erosion and

sedimentation. Installing waterbars on these areas exposed mineral soil which would not have been otherwise placed at risk.

Sedimentation can be reduced through streamside management zones, organic filter strips, or deposits of logging slash. In harvested areas, bare soil from skidding and felling operations is generally spotty. While there is a theoretical risk of soil movement, this movement is often limited to a short distance. Skid trails pose a greater problem. Spreading slash on these trails during harvesting can reduce the impact on especially sensitive areas. This not only reduces the impact of the harvest, but also provides additional means of retarding overland water flow after the harvest.

A high quality job of tract closure by a contractor can easily be offset by recreational users on ATV's and four-wheel drive vehicles. Every effort should be made to restrict access to the tract by gating and leaving slash piles, cull logs, and other deterrents along skid trails and retired haul roads to assure a fair return from closure activities.

Even though these suggestions were developed as a result of this study, they may have potential applications outside of Virginia. Caution is advised when dealing with regional climatic and soil conditions different from those within the study region.

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Appendix A. Data collection forms.

Weather ______________________________

<u>Universal Soil Loss Equation variables</u>

% BARE SOIL ________

% CANOPY (over bare soil) _______

Soil Reconsolidation (.9 / .45) (.45 if undisturbed)

High Organic Content (Y / N)

% Fine Roots (bare soil) ________

Onsite Storage (0 | | | | 1)

Steps % area ________

% slope _______

Comments: ______________________________

____

____

TRACT DATA

Tract ID ________ Ownership ____________

Access Descrip. ____

____

Date of Harvest __________

Equipment Used ____

____

Aspect _______ Skid Type ____________

Ave. % Slope _____ Skid Dir. up % __________

Area ________ down % ________

No. plots ______

ROADS

Length (haul) __________ (skid) __________

Ave. Width (haul) _____ (skid) __________

Truck Turnarounds ____

____

Waterways ____

____

EARTHWORKS

Type	Amount of soil moved	Area	Condtion

Harvest Strategy:

Job Closure (violations to BMP's):

TRACT ID________ DATE __________

LINE ______

PLOT ______

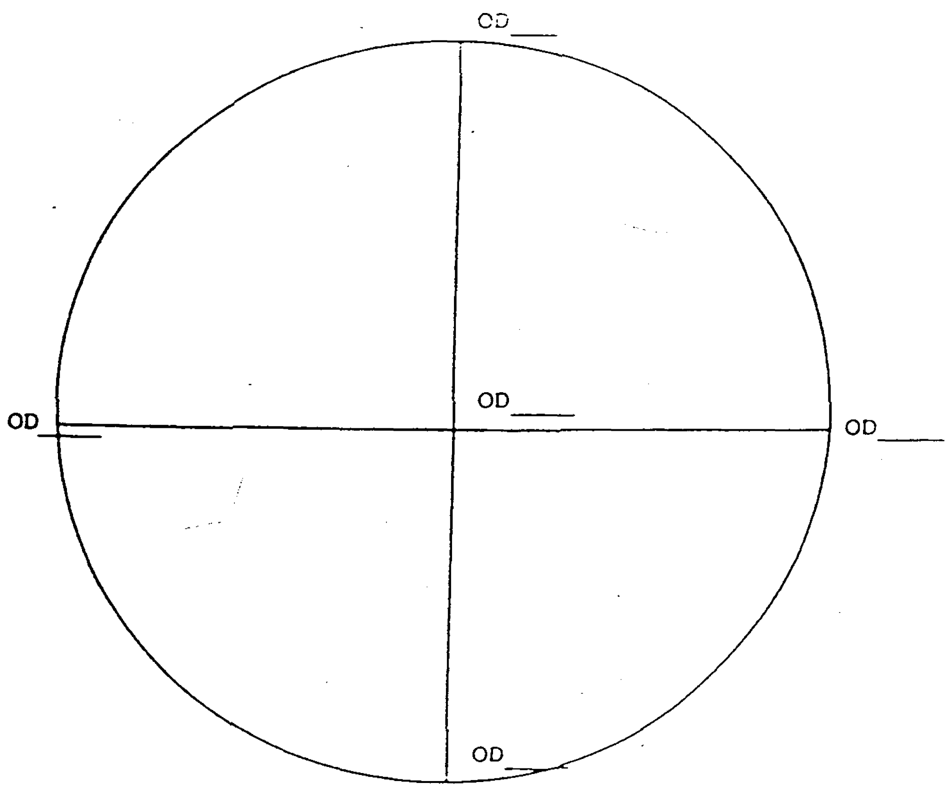
Soil Text(0 - 5)_______

Skid dir(UP / DN / LV / RL)

Brush (CP / LT / MD / HV)

PENETROMETER READINGS

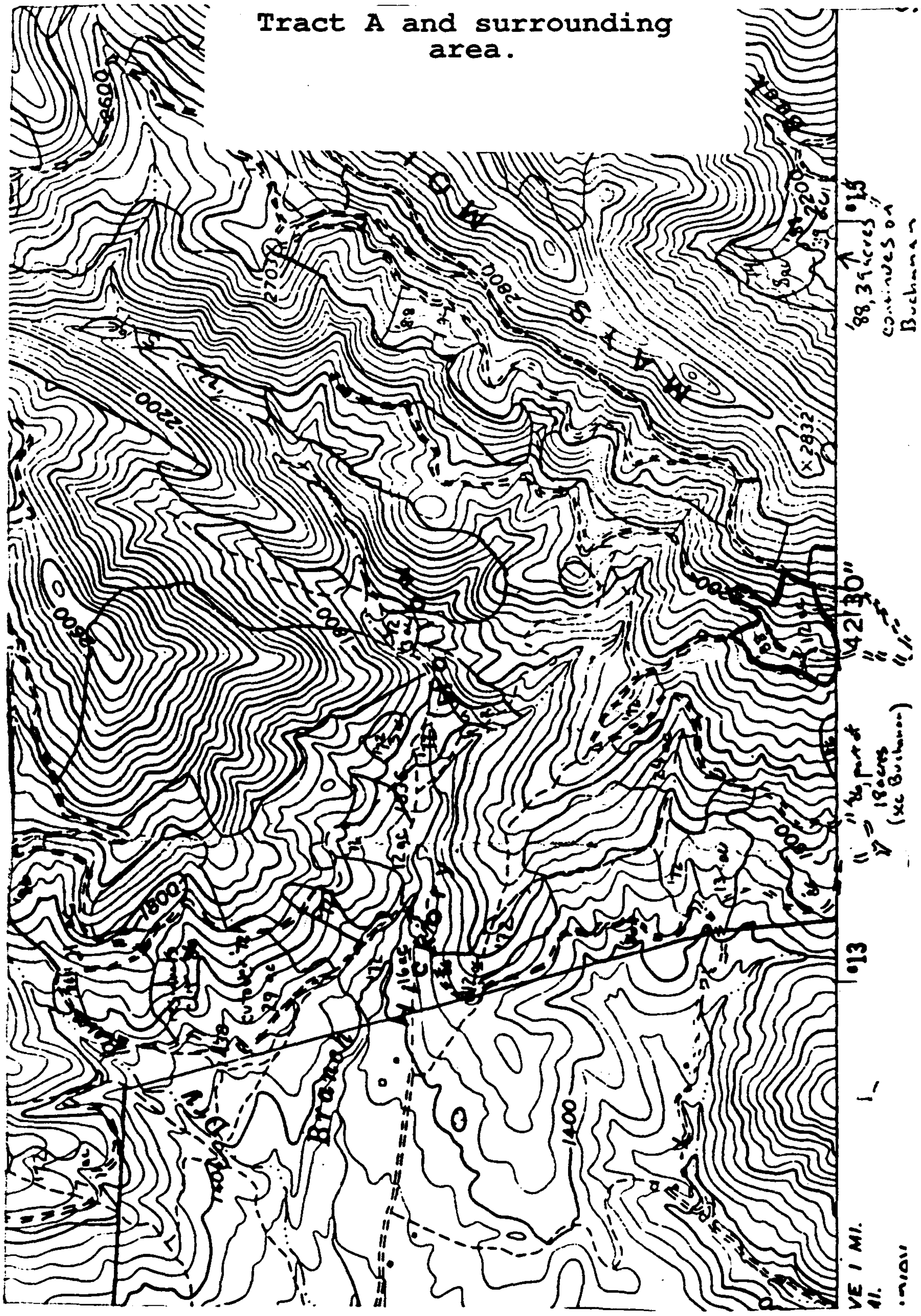
site class				
1"				
2"				
3"				
4"				
5"				
6"				



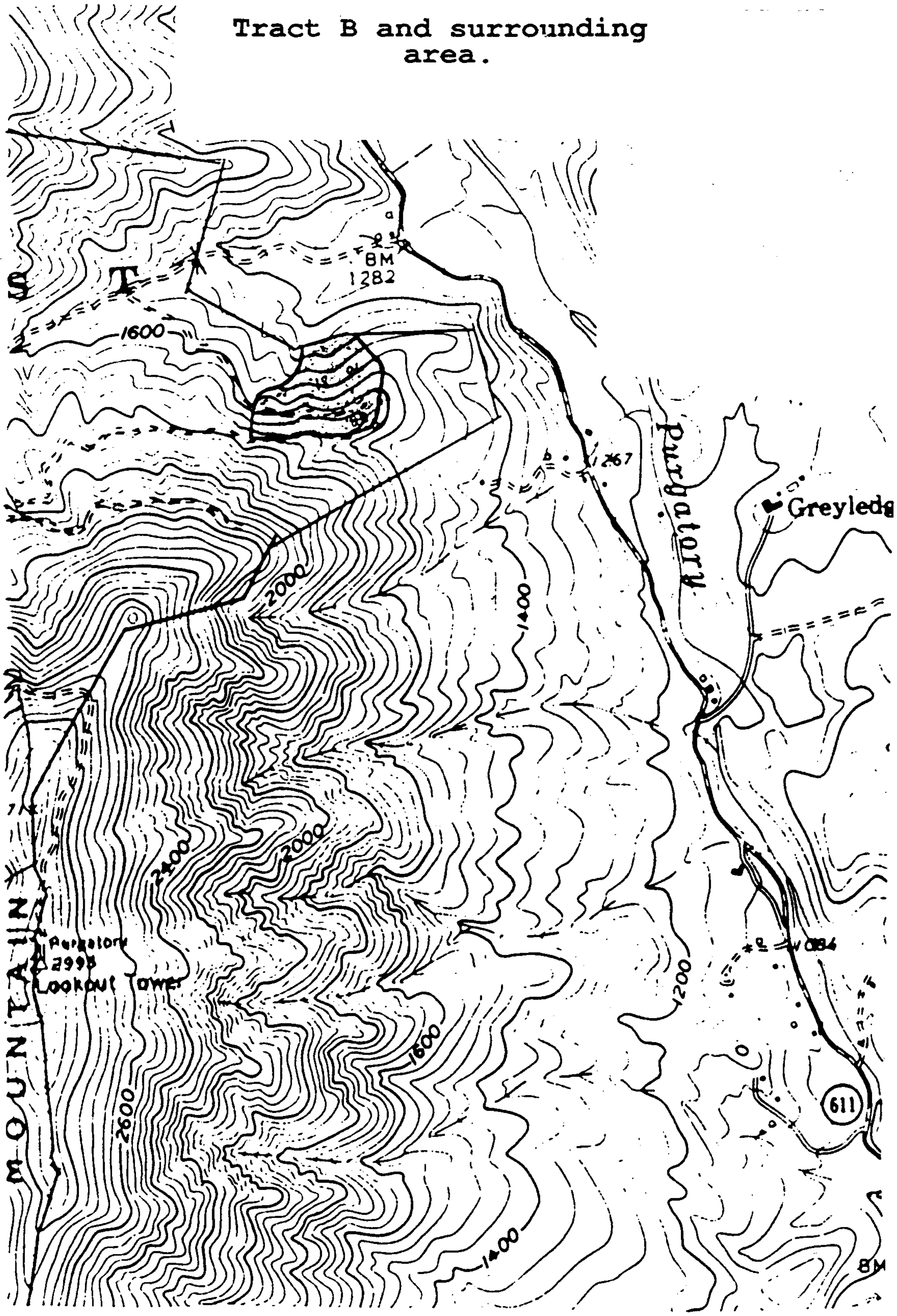
Azimuth __________ Percent Slope __________
Slope Length __________

Appendix B. Topographic maps of study areas.

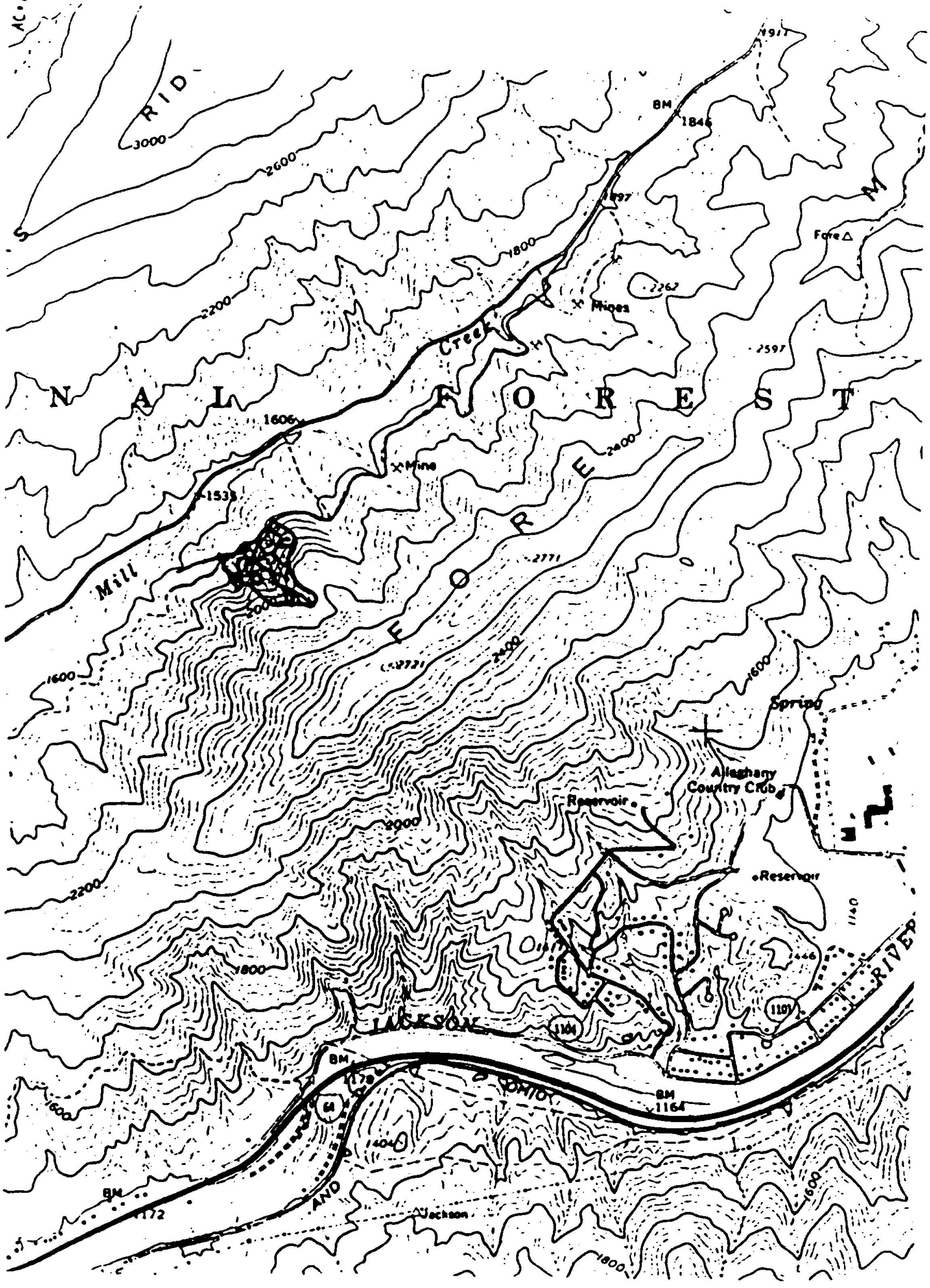
Tract A and surrounding area.

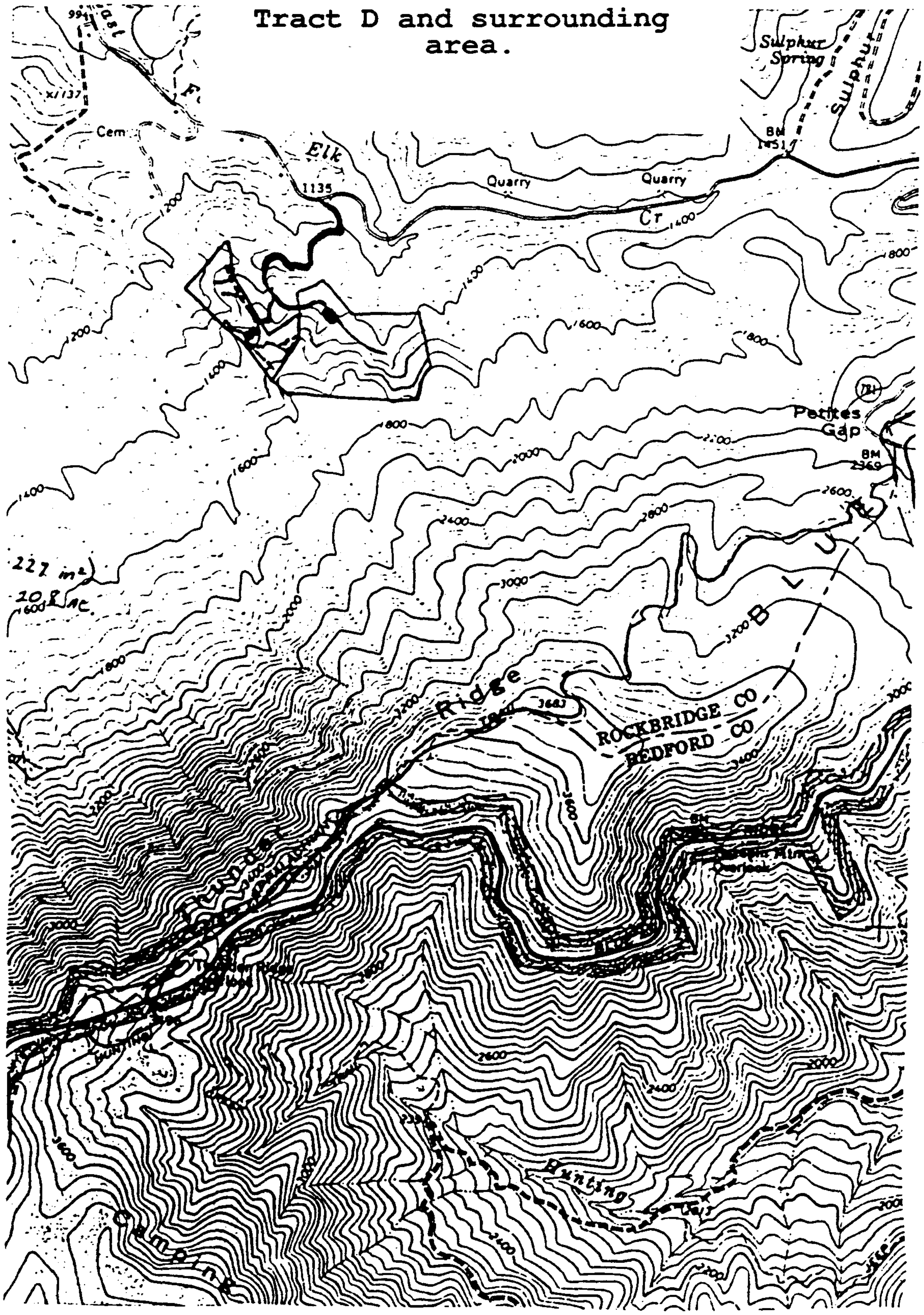


Tract B and surrounding area.

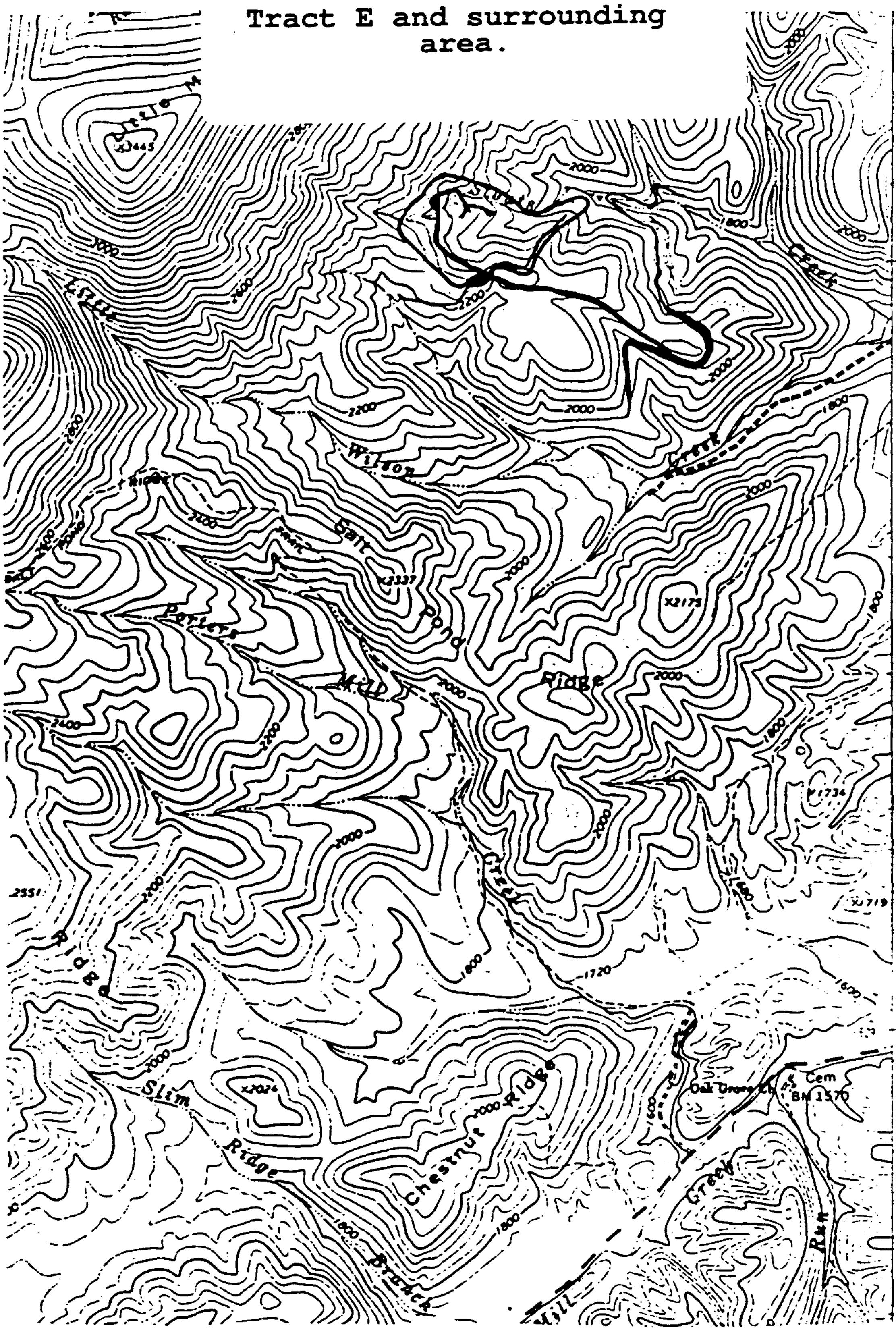


Tract C and surrounding area.

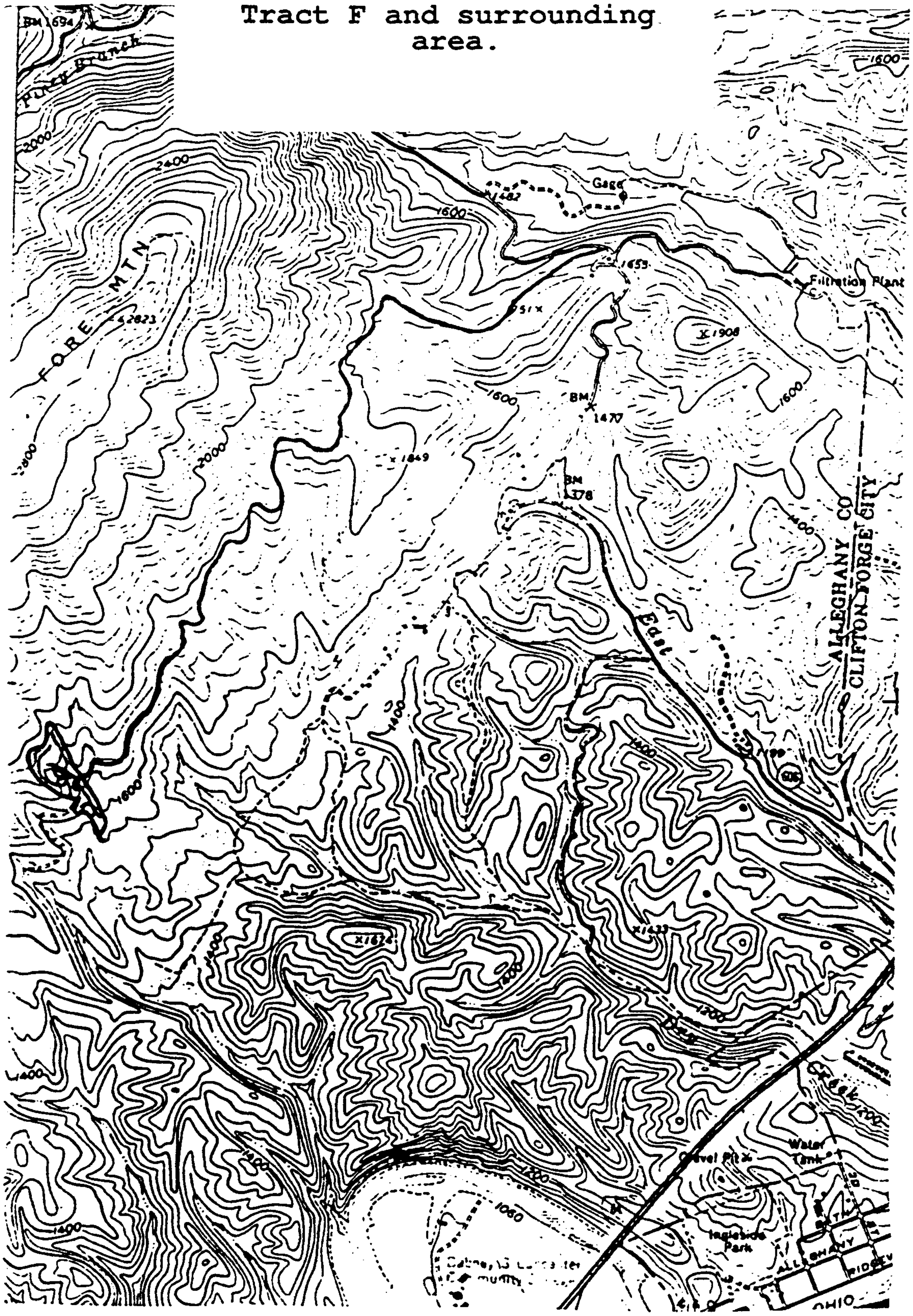


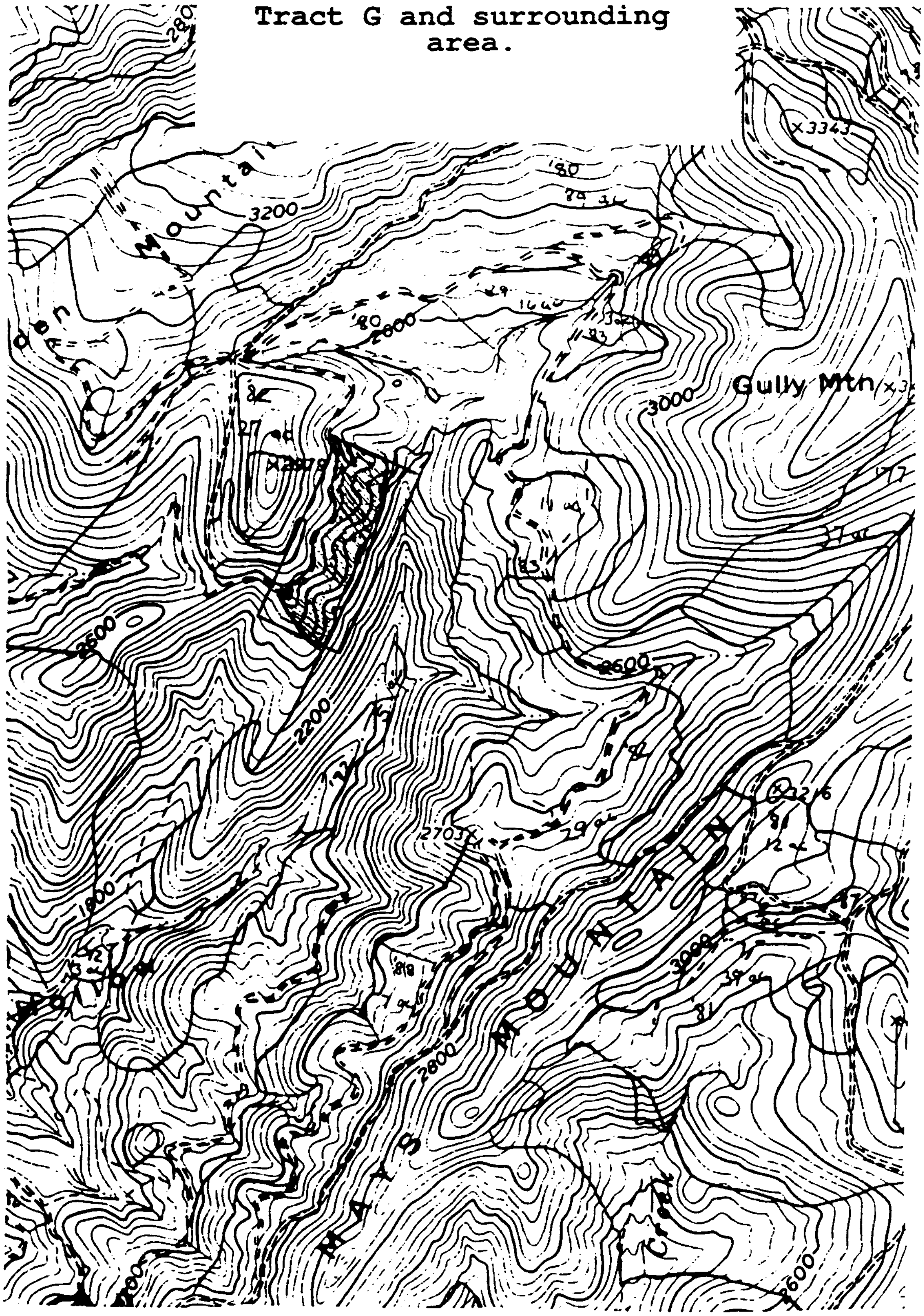

Tract D and surrounding area.
Sulphur Spring
Sulphur
Cem
Elk
Cr
Quarry
Quarry
Peakes Gap
Ridge
ROCKBRIDGE CO
BEDFORD CO
Hunting
227 mi
20.8 ac.

Tract E and surrounding area.

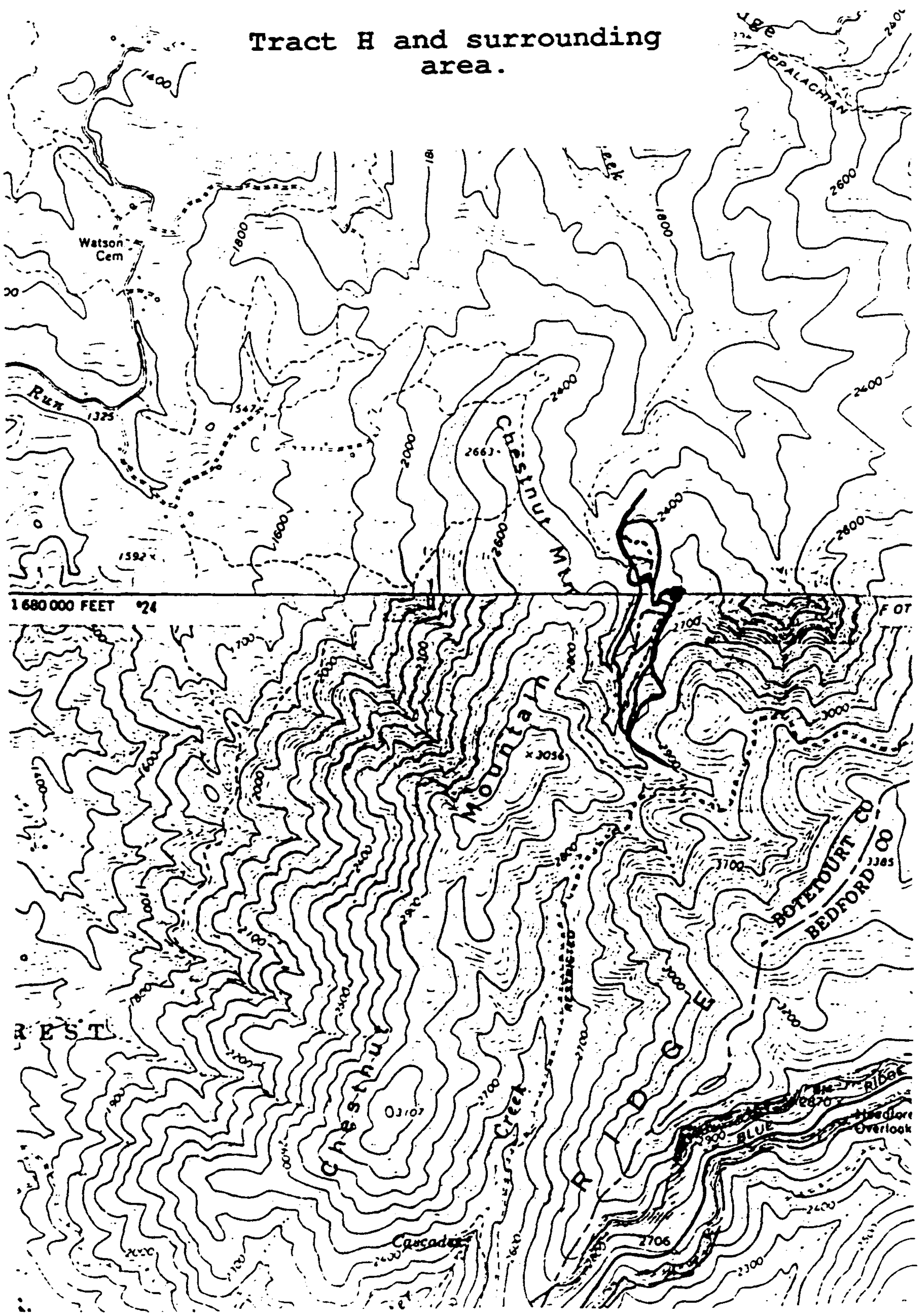


Tract F and surrounding area.

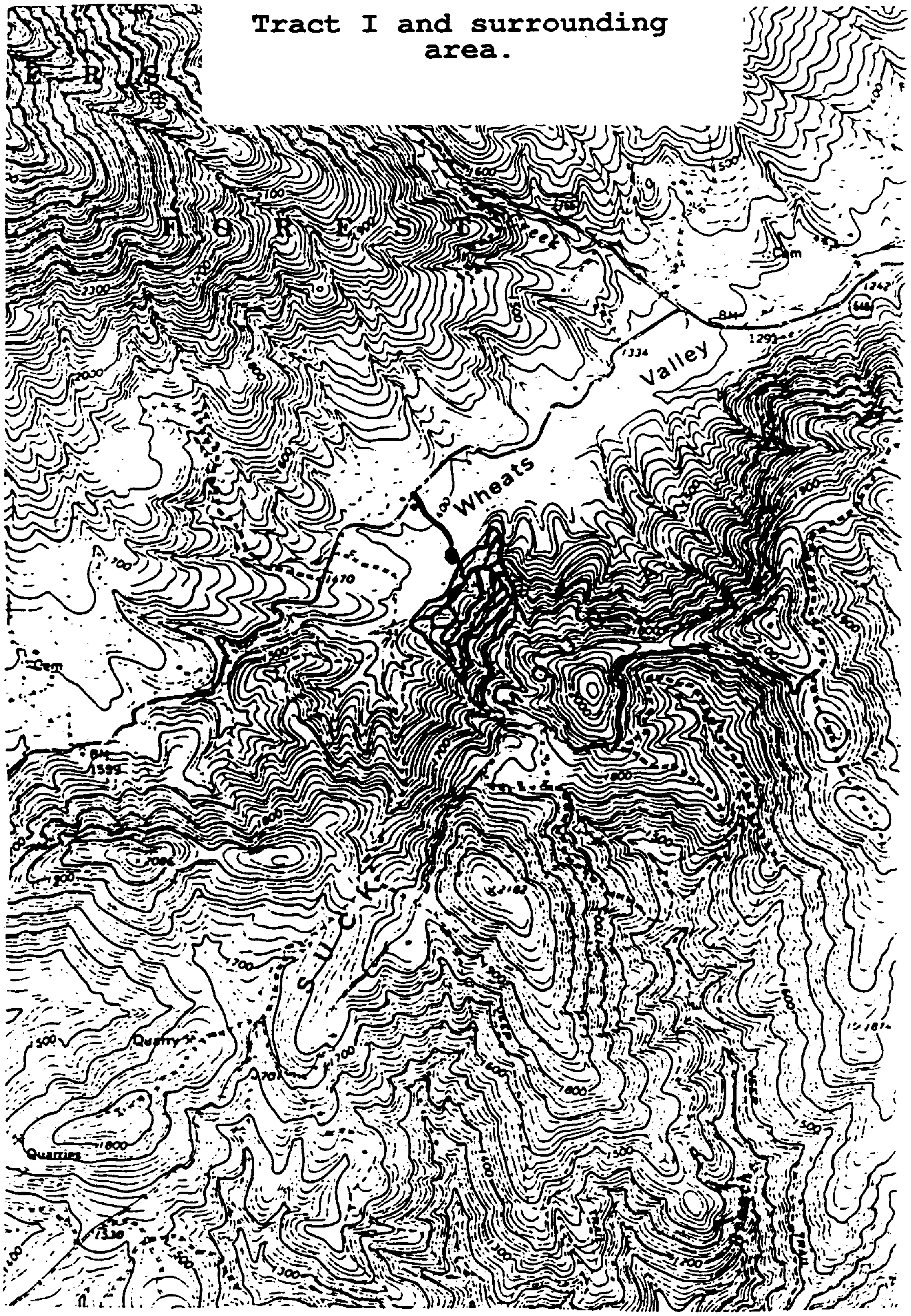



Tract G and surrounding area.
3200
2800
3000
Gully Mtn
2600
2200
1800
2703
MAYS MOUNTAIN
x3343
Creek

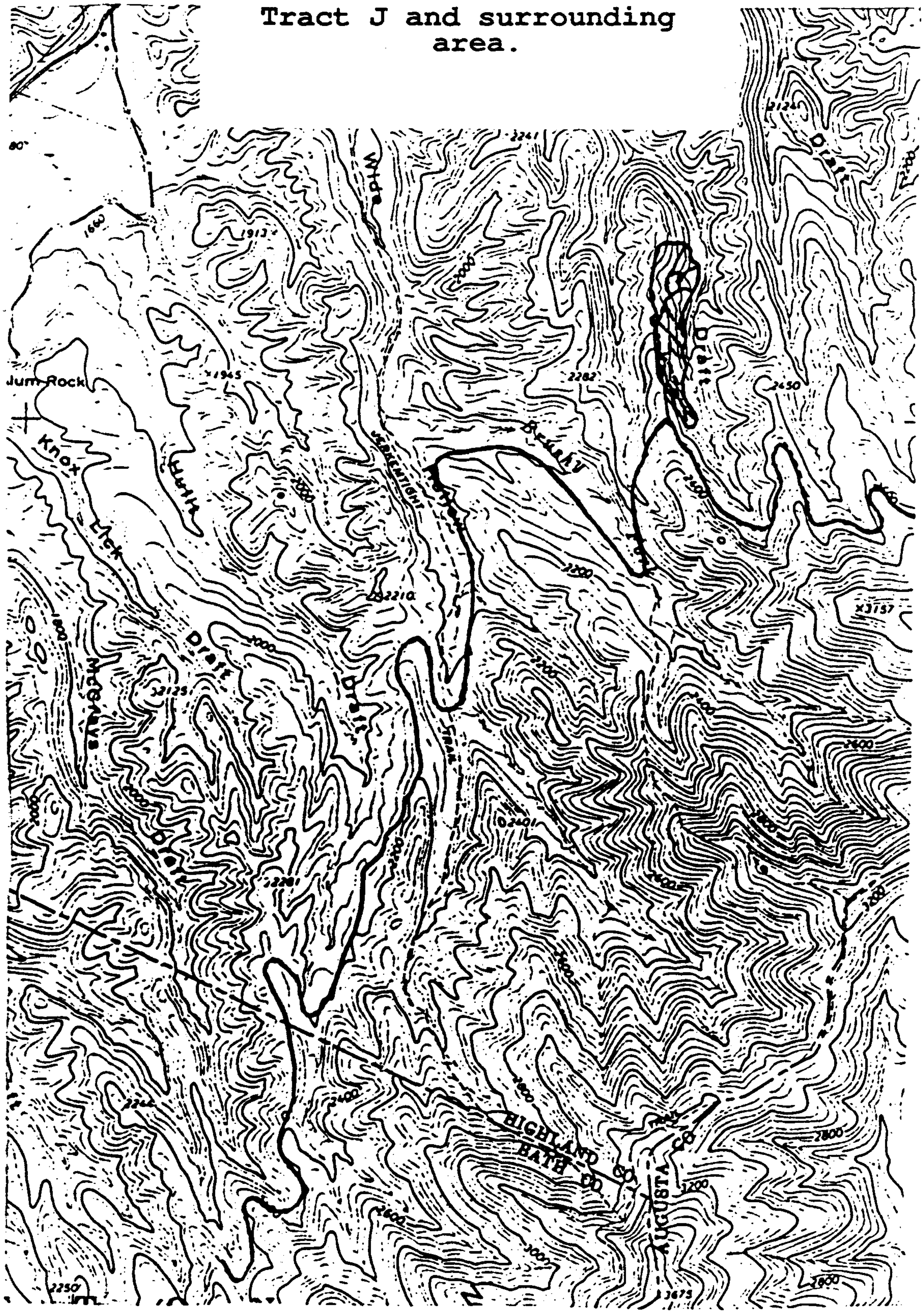
Tract H and surrounding area.



Tract I and surrounding area.



Tract J and surrounding area.



Vita

The author was born and raised in Charleston, West Virginia. He graduated from George Washington High School in 1984 and was admitted into West Virginia University.

During the course of his study at WVU, he was employed two consecutive summers by Westvaco Corporation; he graduated Cum Laude with a Bachelor of Science degree in Forest Resource Management in 1988.

He was accepted into Graduate School at Virginia Tech in the Industrial Forestry Operations program where he received a Master of Science degree. Upon completion he was hired by Procter and Gamble Cellulose Company - Memphis, Tennessee.